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AN INVESTIGATION INTO THE SILVICULTURE AND ECONOMICS

by

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ABSTRACT

The silvicultural practice in plantations of *Eucalyptus saligna* in South Africa was examined. Observations on a large number of sample plots were analysed statistically and recommendations made for establishment, espacement, thinning, pruning and regeneration. Yield tables for unthinned and thinned stands were prepared. The efficiency of felling and subsequent primary conversion was investigated through time studies and the costs of these operations analysed.

The rotation of *E. saligna* stands was discussed on the basis of the yield tables and cost figures from a large number of plantations. Production costs and profits were analysed.

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FOREWORD

The foundation for this publication is a thesis accepted for the Degree of Doctor of Forestry at the University of Stellenbosch in December, 1959.

The work was initially undertaken at the suggestion of Professor J. H. Becking who recognised the need for a systematic investigation of one of the most important species in South African Forestry. For his encouragement and competent advice the author is grateful.

He wishes also to make grateful acknowledgement to:

Professors C. L. Wicht and P. P. du Toit Deetlefs, both of whom were promotors of the thesis. To the former he is grateful for his introduction to S.A. Forestry and valuable advice during the execution of the project; to the latter for outstanding criticism during the preparation of this publication.

The Secretary of Forestry, Mr. D. R. de Wet and his staff, for making available numerous data for incorporation into this study.

Mr. C. S. Hubbard, for painstakingly correcting the English translation.

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This study would have been impossible without the assistance of the private saligna growers. The co-operation of the following companies and persons is grateful acknowledged: Westfalia Estate, S.A. Forest Investments, Rand Mining Timber Co., S.A. Pulp and Paper Industries, S.A. & General Investment and Trust Company, Saligna Forestry Company, Exchange Yard, Atherstone and Brooks, Prins Bros., and Messrs. Rottcher, Plange and Hathorn.

INTRODUCTION

In South Africa the name *Eucalyptus saligna,* or saligna gum, is commonly applied to trees of the related species *Eucalyptus grandis* (Hill) Maiden and *Eucalyptus saligna* Smith and also to trees of the many transitional forms between them. Actually, the bulk of the plantings is strictly *Eucalyptus grandis* or the intermediate forms, showing greater affinity with E. grandis. There is comparatively little true *Eucalyptus saligna.*

In this publication, because of the botanical and silvicultural affinities between the two, and for the sake of clarity, the two species and the intermediate forms are referred to as *Eucalyptus saligna* or Saligna Gum.

Eucalyptus saligna was introduced from Australia during the second half of the nineteenth century and planted in various parts of South Africa. With the development of the Transvaal gold mines there arose a great demand for mining timber which could be quickly and cheaply produced. *E. saligna* was a suitable species, suitable land for growing it rapidly and cheaply was available and there soon followed a marked increase in the area planted with this eucalypt.

In 1920 the Department of Forestry decided to restrict the planting of *E. saligna* for the production of mining timber in State plantations and this decision paved the way for private enterprise to expand the area of rapidly growing, short rotation *E. saligna* to meet the ever-increasing demands of the mining industry.

About the same time investigations by the Forest Products Institute of the Department of Forestry showed that the timber of E. saligna was suitable for purposes other than mining timber e.g. for box shooks, parquet flooring, office and other furniture. This led to an increased demand for logs of dimensions greater than those required by the mining industry.

The period of the second world war and the years that followed witnessed further changes: the development of the Orange Free State gold fields resulted in a further increase in the demand for mining timber; there was an increased demand for E. saligna pulpwood by the paper and fibreboard manufacturing industries and there arose a large demand by the newly established cellulose manufacturing industry. The scope and range of utilisation had expanded greatly.

The area in South Africa planted with Eucalypts, all species, has been:

Year	*Area* (acres)
1937	300,526
1946	408,356
1950	375,888
1955	361,300

That there should have been small decreases in the planted areas in 1950 and 1955 is attributable to a reduction in the area of slow growing species of Eucalypts, rather than to a decrease in the area of *E. saligna.* Of the gross figure of 361,000 acres at the 1955 forest census the area planted with *E. saligna* was 241,516 acres or almost 67% of the total. This figure of 241,516 acres amounted in fact to 13% of the total area in South Africa, afforested with exotic species.

The distribution in ownership of the 1955 area is also of interest and is:

	Area (acres)	Percentage of total
Privately owned plantations	220,991	91.5
State owned	15,400	6.4
Owned by Public Bodies	5,125	2.1
Total	241,516	100.0

Such then, is the importance of *E. saligna* as a source of raw material to the primary and secondary industries of South Africa.

Scope and Object of Investigation.

Principally because the bulk of E. saligna plantations in South Africa is in private ownership the Department of Forestry has not instigated systematic investigations into the silviculture of the species. In consequence management of plantations has tended to be arbitrary.

In this investigation the existing silvicultural practice has been examined. Based on a statistical analysis of the measurement of a large number of sample plots, recommendations are made with the object of improving existing silvicultural practice, and ensuring higher yields, improved financial returns and a better quality of timber.

To this end 397 sample plots were measured in stands varying in age, site quality and thinning régime. Yield tables, based on these measurements, have been prepared.

The distribution of the sample plots is:

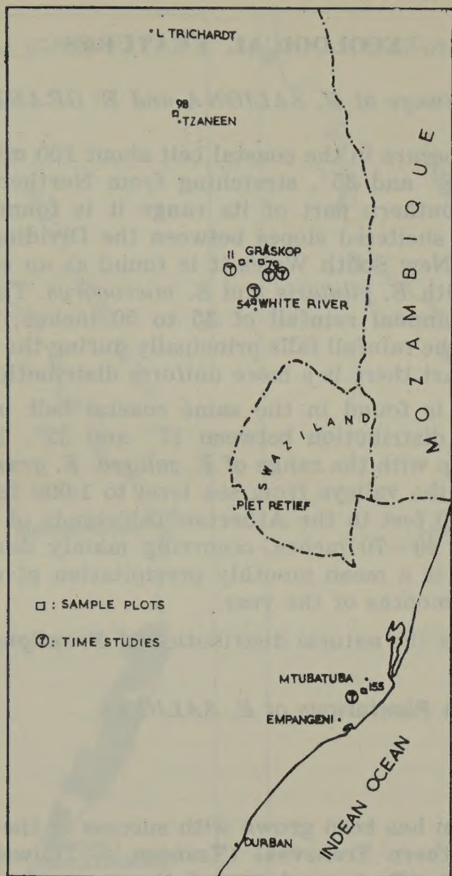
Region	Plantation	No. of sample plots
N. Transvaal	Westfalia Estate	66
,,	Rooikoppies	14
,,	Other Plantations	18
E. Transvaal	S.A. Forest Investments	74
,,	Rand Mining Timber Co.	16
,,	S.A. Pulp and Paper Industries	34
,,	Other plantations	20
Zululand	S.A. General Investment and Trust Co.	121
,,	S.A. Forest Investments	26
,,	Hathorn	8
	Total	397

In 14 sample plots, in young stands, only the mean height of the stand was measured. In the remaining 383 sample plots sizes were:

Size (acre)	No. of plots
Smaller than 0.10	3
0.11—0.20	36
0.21—0.30	230
0.31—0.40	76
0.41—0.50	27
0.51—0.60	1
0.61—0.70	6
0.81—0.90	3
1.01—1.10	1

The weighted average plot area was 0.287 acre.

Figure 1.



Location of plantations where sample plots were established and time studies made.

Diameters, breast high were measured with calipers and recorded in 1 inch classes. In each plot total tree height and length of living crown of fifteen sample trees regularly distributed over all diameter classes were measured with a Blume-Leisz hypsometer.

Time studies were used to investigate the efficiency of felling operations and subsequent primary conversion. These were made at:

Waterhoutboom and Driekop Plantation of S.A. Forest Investments (E. Transvaal); Roodewal Plantation of Rand Mining Timber Co. near Graskop; Plantations of S.A. Pulp and Paper Industries near White River; Plantations of S.A. General Investment and Trust Co., Kwambonambi.

Figure 1 shows the location of plantations where sample plots were established and where time studies were made.

CHAPTER I

ECOLOGICAL FEATURES

1. *The Natural Range of E. SALIGNA and E. GRANDIS in Australia.*

E. saligna occurs in the coastal belt about 100 miles wide between South latitudes 28° and 35°, stretching from Northern Queensland to Sydney. In the Southern part of its range it is found in pure stands in valleys and on sheltered slopes between the Dividing Range and the sea. In Northern New South Wales it is found at an elevation of 4,000 feet in mixture with *E. pilularis* and *E. microcorys*. The climate is subtropical with an annual rainfall of 35 to 50 inches; in the Northern part of the range the rainfall falls principally during the summer months; in the Southern part there is a more uniform distribution.

E. grandis is found in the same coastal belt but with a wider South latitudinal distribution between 17° and 32°. There is thus an appreciable overlap with the range of *E. saligna*. *E. grandis* is also found in pure stands in the valleys from sea level to 1,000 feet in New South Wales and to 2,500 feet in the Atherton Tablelands of Queensland. The annual rainfall is 40—70 inches, occurring mainly during the summer months but there is a mean monthly precipitation of at least one inch during the driest months of the year.

Fig. 2 shows the natural distribution of *E. saligna* and *E. grandis*.

2. *South African Plantations of E. SALIGNA.*

(a) *Climate.*

Saligna gum has been grown with success in the warm temperate zones of the Northern Transvaal (Tzaneen — Duiwelskloof) and the Eastern Transvaal (Eastern slopes of the escarpment near Graskop, White River, Barberton) and in the subtropical zone in Zululand. It has also been grown in the humid colder zone of the Eastern Transvaal (Driekop) and in the sub-humid colder zone near Piet Retief but on a smaller scale and with less spectacular results. Plantations are also found in the coastal and semi-coastal belt in Natal, South of Empangeni. All of the areas in South Africa where saligna gum has been extensively planted enjoy the summer rainfall.

Whilst it has not been intensively grown in the winter rainfall region there are, nevertheless, some stands of good quality to be found there.

The sites in the Transvaal where saligna gum has been successfully grown correspond with the "Lowveld bushveld" type of Acocks; those in Zululand to his "Coastal forest and thornveld" type.

Rainfall. In the Tzaneen-Duiwelskloof area there is considerable variation in rainfall. Mean annual rainfall at Woodbush, Westfalia and Rooikoppies is respectively 69, 54 and 58 inches. In the Duiwelskloof area it is only 41 inches. A similar variation is found in the Eastern Transvaal. Mean annual rainfall at White River is 36 inches, at Waterhoutboom

Figure 2.

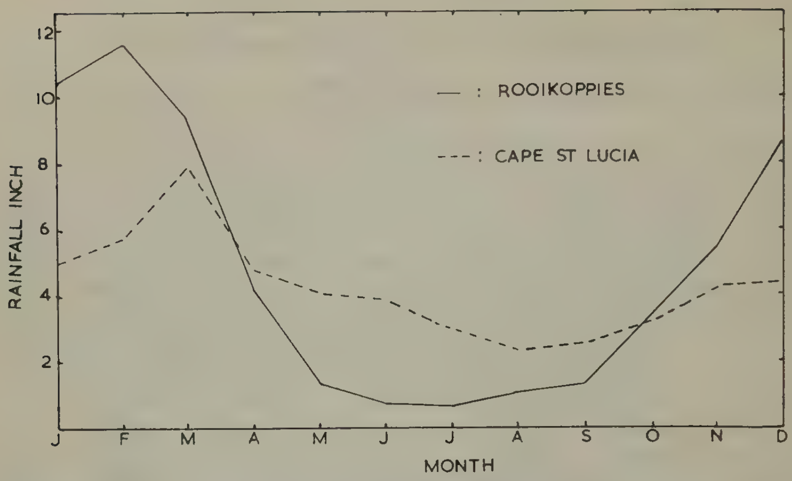
Natural distribution of *E. grandis* and *E. saligna.*

and Doornlaagte, east of Graskop, it is approximately 60 inches and at Graskop 69 inches.

In the Kwambonambi-Mtubatuba area in Zululand the mean annual rainfall is in the 40—50 inch bracket, but in a narrow strip near the coast it increases to 60—70 inches.

It will be seen from figure 3 that rainfall in Zululand is more uniformly distributed than it is in the Transvaal.

Figure 3.



Distribution of rainfall for the localities Rooikoppies (Transvaal) and Cape St. Lucia (Zululand).

Temperature. In figure 4 temperature diagrams are given for the meteorological stations at White River (Transvaal), Dukuduku (Zululand), Maryborough and Wollongong (Australia).

The curves indicate the fluctuations in temperature throughout the year whilst the distance between the curves for each station indicate the extent of the mean daily fluctuations. The White River climate differs slightly from that of Dukuduku; there are also differences in climate between Maryborough and Wollongong. But the range of temperature in areas in South Africa, where *E. saligna* has been planted on any scale, is appreciably greater than that encountered in the natural range of distribution in Australia. Also the smaller daily and monthly fluctuations at Maryborough and Wollongong indicate that the climate in the natural range is more equable.

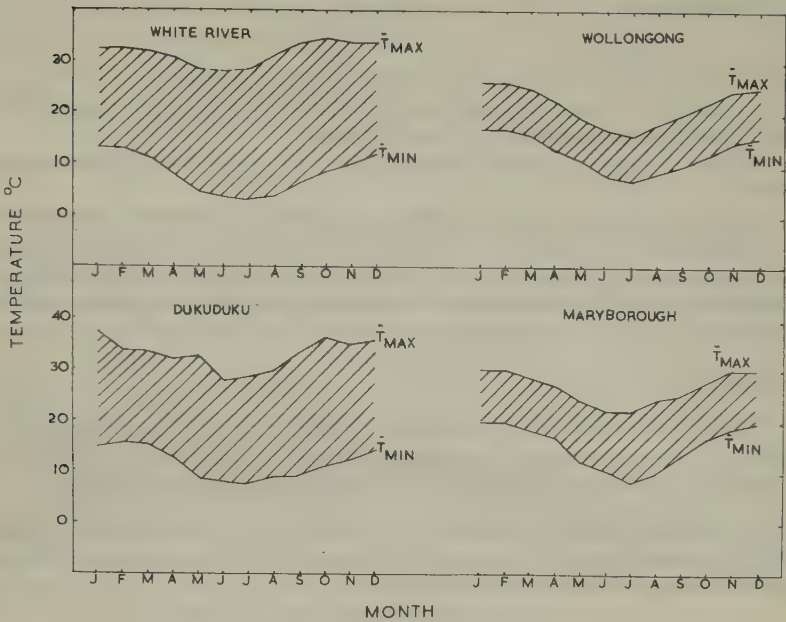
(b) *Soils.*

There are important differences in soil types and fertility between plantations in the Transvaal and in Zululand.

The Transvaal plantations are generally on soil types morphologically and chemically classified as Laterites and Lateritic Red Earths (Van der Merwe 1940). The high rainfall of the region leads to a rapid decomposition of the parent material and a complete mineralization of the organic material. The soil is red or reddish-brown in colour. The geological formation varies from granite in the Tzaneen-Duiwelskloof area to dolomite and sandstone in the Graskop area. In Zululand the plantations are located on a coastal belt of sand dunes running parallel with the coast. There is slight variation in colour and texture of these sands most of which are almost white in colour.

In addition to the differences in soils in Transvaal and Zululand plantations there are marked differences in the topography of the

Figure 4.



Temperature diagrams for metereological stations within the natural range and within South Africa.

ground. In the Transvaal the surface relief is irregularly undulating; in Zululand the country is almost flat.

3. *Potential Injurious Factors.*

(a) *Wind.*

1 to 2 year old coppice stands are frequently damaged by wind to the extent that it might become necessary to clear and recoppice. Dense 4—5 years old stands on exposed sites may also suffer damage in this way, and such damage is frequently encountered, particularly in planted stands, on those sites in the Northern Transvaal. Early, heavy thinnings reduce the risk of damage.

(b) *Drought.*

Drought losses after planting may occur, particularly in the Zululand coastal belt. Similar losses may occur in older stands which are established on shallow soils.

(c) *Frost.*

Frost is rarely experienced in Zululand, but damage is occasionally done to young stands in the Transvaal particularly on exposed sites. Such damage in young coppice stands can sometimes be obviated by arranging

felling operations so that the new coppice growth has time to harden before frost occurs.

(d) *Insects and Termites.*

E. saligna is not susceptible to attack by the Eucalyptus Snout Beetle *Gonipherus scutellatus* (Tooke 1955).

Felled trees are readily infested by the borer *Phorocantha semipunctata.*

In the nursery injury to plants is sometimes caused by caterpillars.

Termites occasionally attack the lower part of the stem of *E. saligna* trees and if the cambium is extensively damaged the trees die. This type of attack occurs more frequently in initial plantings rather than in second and third rotation stands.

(e) *Diseases.*

Heartrot frequently develops in 30—40 year old stands; in Zululand it has developed in stands 10—15 years old. There is no evidence that this heartrot infection is confined to coppice stands.

(f) In Zululand plantations mortality of individual trees in a stand may occur. The cause has not been definitely established, it may well be due to suppression and water shortage.

CHAPTER II

CURRENT SILVICULTURAL PRACTICE IN E. SALIGNA PLANTATIONS IN SOUTH AFRICA

a. *Seed collection.*

All too frequently seed collection is combined with felling operations and inadequate attention has been paid to the quality and vigour of the parent trees. The importance of collecting seed from selected parent trees is becoming increasingly recognised.

b. *Nursery Practice.*

Seedlings are raised in open beds, the seed being sown about three months before the plants will be required for planting. The soil in the seed beds is usually mixed with organic manure.

4—6 Weeks after sowing, when the seedlings have produced 4—6 juvenile leaves, they are pricked out into wooden trays, 25—30 transplants per tray. In the seedling stage watering should be done carefully to avoid losses through "damping off".

c. *Soil preparation.*

Whenever possible and after the natural vegetation has been burnt, the soil is prepared by ploughing and is then harrowed.

In parts of Zululand strip preparation has replaced complete preparation with resultant reduction in costs. In this operation a rotary hoe and not a plough is used for the preparation of the strips.

In some plantations in the White River area, the ground is intensively prepared and the planting of the site is combined with the production of an agricultural catch crop.

Where ground is reforested no preparation beyond pitting is necessary.

d. *Planting.*

In the Transvaal, the best months for planting are December and January, when rainfall is normally high. In Zululand the best results are usually obtained with June and July plantings. During this period soil temperature is relatively low and insect activity is less serious. In this area planting can also be done in September and October but the month of August is not recommended, because of the frequency of hot desiccating North and North East winds which may be the cause of serious losses. Planting during the period November to March should be avoided.

It has been found in Zululand that watering each plant with about half a gallon of water at the time of planting gives beneficial results. If the relative humidity is extremely low at this time it is advisable to repeat this operation. The water-retaining capacity of soils in the Transvaal is much higher and, as rainfall during the planting period is high, watering at the time of planting is not necessary.

Planting espacement varies from 6 x 6′ to 12 x 12′; 9 x 9′ is that most generally adopted. Square planting, in which the distance between the trees is the same in either direction is usually done. In certain plantations in the White River area plants have been spaced 4—6 feet apart in the rows which are 12—14 feet apart. Two advantages are claimed for this arrangement:

(1) Weeding between the rows can be done mechanically at low cost.

(2) Transport vehicles can be taken into the stands when intermediate or final yields are exploited.

Even when planting is well done and the circumstances are favourable there will usually be some failures. This mortality varies widely and is usually higher in Zululand than in the Transvaal. In the former a mortality of 20% to 25% or even higher is common whilst in the latter region it is generally not more than 10% to 15%. The replacement of these failures (blanking) may not always be necessary in the Transvaal. It is common practice to do so in Zululand.

Stands should be blanked as soon as possible after and preferably within a month of planting. A delay may result in less favourable weather for the operation. Moreover the replacement plants may not only be handicapped by competition from regrowth of the ground flora but also permanently suppressed by the earlier planted and more vigorous neighbours.

Subsequent weeding may not be necessary; if the young trees grow vigorously they will themselves suppress the natural vegetation. Generally and particularly in Zululand it is necessary to cut back plant growth around the young trees during the first year after planting.

e. *Tending.*

Tending regimes vary from plantation to plantation, not only because plantations managed for the production of mining timber require different treatment from those managed for the production of sawn timber, but also because of wide differences in the treatment accorded to plantations which produce saw timber. The following examples illustrate this latter variation:

1. Westfalia Estate. Three heavy thinnings at 4½—5½, 7—8 and 11—13 years are carried out.
2. S.A. Forest Investments. By a combination of a wide espacement (11 x 11′) and a short rotation (11—14 years) thinnings have been eliminated.
3. Zululand. In most plantations two light thinnings, in the seventh and at 10—12 years are carried out. Only suppressed trees are removed.

These wide differences emphasize the importance of instituting thinning research experiments.

In plantations managed for the production of mining timber and pulpwood, there is no thinning.

f. *Pruning.*

A high yield of knot-free timber is important in the production of saw timber, it is of less importance in the production of mining timber and it could be of importance in the production of wood pulp. Following is the regime applied by S.A. Forest Investments: Trees are pruned to half the height when the stands attain a mean height of 12—15 feet. A second pruning extending to 18—20 feet is given when the stands are 6—7 years old. Both prunings may remove living as well as dead branches.

g. *Rotation:*

At Westfalia, where primarily saw timber is produced, the rotation is about 20 years. In the E. Transvaal, the rotation for saw timber production is 12—14 years whilst in Zululand similar plantations are managed on a 14—15 year rotation.

In the mining timber industry, the greatest demand is for poles with a diameter of 3½—6 inches and for this kind of production a rotation of 6—8 years is used. Nevertheless, stands planted at a 9 x 9′ espacement and grown on a rotation of 7 years, produce a considerable amount of large sized wood for which there is but a small demand by the mining industry. In part this oversized excess has been absorbed by saw mills. In the case of some plantations however, a still shorter rotation has been adopted. For pulpwood production in Zululand the rotation is 7—9 years.

1. *Regeneration.*

It has been general practice for planted *E. saligna* stands to be followed by one or more coppice rotation. This practice has been

abandoned at Westfalia where succeeding rotations will be established by replanting. The main reasons for this are:

(i) The important aspect of selecting the best quality stems for the final crops can be more effectively accomplished in planted stands rather than in coppice.

(ii) In the longer rotation saw timber stands, stump diameters are greater, the overgrowing of the original stumps takes much longer and the danger of attack by heartrot fungi is increased.

(iii) The cost of establishment, expressed as a percentage of the total cost of production, decreases with increasing length of rotation. Consequently the difference in cost between coppice and transplant regeneration is not a factor of such importance in the longer rotation.

In coppice regeneration, methods of cleaning vary. The reduction of the coppice shoots to one per stool, may be done in three operations during the first year, in other plantations it is done, sometimes in two operations and in some cases in one. The more gradual reduction in three operations is to be preferred as it reduces the risk of wind injury.

Reduction of coppice is sometimes combined with fencing dropper production and in this case the reduction has to be delayed until shoots have attained the minimum diameter required for droppers. The second and third reduction may be made one or two years later.

In most cases coppice regeneration connotes the leaving of only one shoot per stool. Occasionally however, in irregular stands, where as a result of repeated coppice regeneration a low number of living productive stumps remains, it is the practice to leave two shoots per stool. This type of treatment is to be found in some plantations in the Northern Transvaal and in Zululand.

CHAPTER III

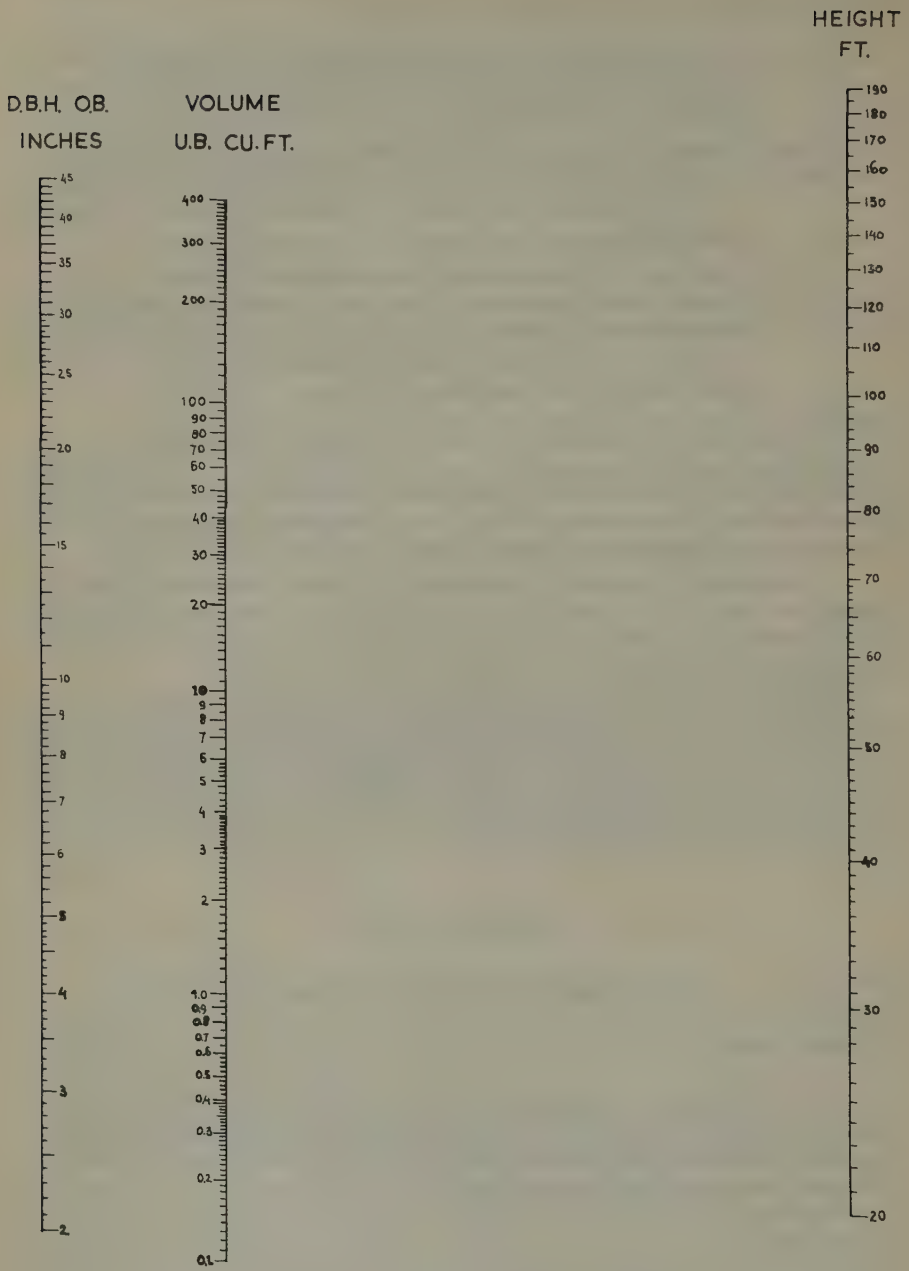
STEM VOLUME AND FORM

1. *Stem Volume.*

An alinement chart based on the measurement of 357 E. saligna trees, in 10 feet sections, by the Department of Forestry has been prepared by Mr. E. K. Marsh of that Department. Permission to produce this chart is gratefully acknowledged.

2. *Stem Form.*

In an investigation of the stem form of *E. saligna* the measurements of the 357 *E. saligna* trees were used. The breast height form factor, i.e. the ratio of stem volume to the product of basal area at breast height and tree height was unsuitable to describe the form, because it is affected by both tree height and d.b.h.



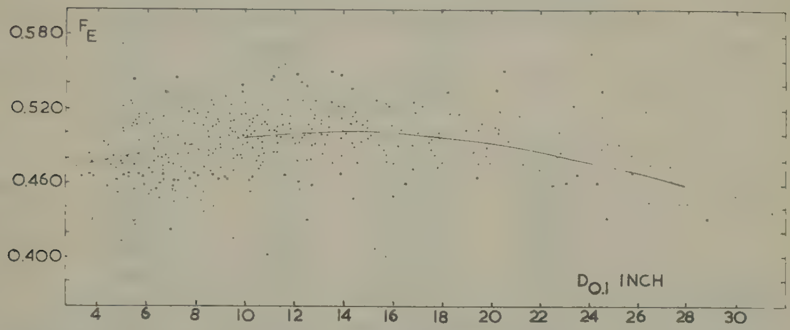
ALIGNMENT CHART FOR E. *SALIGNA*.

(based on 357 sample trees measured by the Forest Research Institute of the Department of Forestry).

Because of this the investigation was based on the true form factor, in which the breast high basal area is replaced by the basal area at 10% of the total tree height. There is a correlation between stem taper and true form factor but it has to be borne in mind that taper and form factor are two distinct concepts, the former referring to decrease in diameter as one proceeds up the stem and the latter to volume. Because of this it was necessary to investigate form factor and taper separately.

In the study, a stem curve was drawn for each stem and the true stem form factor for each calculated. This factor was then plotted against diameter at 10% of the tree height ($d_{0.1}$) and a curve fitted to the points (figure 5). It showed that the true stem form factor, increases with $d_{0.1}$, reaches a maximum and then decreases. This decrease is probably due to the increasing volume of branchwood which develops in the upper stem as the trees grow older. Because this form factor is based on stem volume only, excluding branchwood, it is lower than the true form factor which strictly refers to total tree volume, i.e. stem plus branchwood volume.

Figure 5.



Relation between diameter at 10% of tree height ($d_{0.1}$) and true form factor (F_e).

It can be expected and has actually been found in practice, that the difference between the stem form factor and tree form factor will become greater as the trees become older.

Investigations of the taper of *E. saligna* began with the calculation of true form quotients for each tree i.e. the ratio of diameter at a given percentage of total height to diameter at 10% of total height. The form quotients calculated were:

$$\eta_{0.3} = \frac{d_{0.3}}{d_{0.1}} \qquad \eta_{0.7} = \frac{d_{0.7}}{d_{0.1}}$$

$$\eta_{0.5} = \frac{d_{0.5}}{d_{0.1}} \qquad \eta_{0.9} = \frac{d_{0.9}}{d_{0.1}}$$

where $d_{0.1}$, $d_{0.3}$, etc. refer to the diameter at 10%, 30% etc. of the total height of the tree.

In each group the form quotients were plotted against $d_{0.1}$, and a curve fitted. It was found that the form quotient $\eta_{0.3}$ was not correlated with $d_{0.1}$, but the form quotients $\eta_{0.5}$, $\eta_{0.7}$, and $\eta_{0.9}$ increase with increasing $d_{0.1}$, rise to a peak and then decrease. This means that the taper in the stems changes when the trees grow older, but only in the upper part of the stem.

The next thing of importance to examine is the relationship between d.b.h. and the factors $d_{0.1}$ and tree height. A graphical test showed that no correlation exists between tree height and the quotient $d_{0.1}$: d.b.h. for a given diameter class. It was not necessary therefore to introduce tree height as an additional variable and it was permissible to compute the regression of $d_{0.1}$ (u.b.) on d.b.h. (o.b.) which can be represented by a straight line. The result of the computations is given in table 1.

Table 1.

Relation between d.b.h. over Bark and Diameter u.b. at 1/10, 3/10, 5/10, 7/10 and 9/10 of Tree Height.

d.b.h. (inches, o.b.)	Height 0.1 h	0.3 h	0.5 h	0.7 h	0.9 h
	diameter u.b. (inches)				
3	2.70	2.35	1.81	1.17	0.43
4	3.73	3.14	2.43	1.59	0.59
5	4.55	3.83	2.99	1.99	0.73
6	5.37	4.52	3.55	2.38	0.89
7	6.19	5.21	4.14	2.81	1.05
8	7.00	5.89	4.71	3.23	1.22
9	7.82	6.58	5.30	3.68	1.40
10	8.64	7.27	5.88	4.13	1.56
11	9.46	7.96	6.47	4.59	1.71
12	10.28	8.65	7.08	5.04	1.87
13	11.10	9.34	7.66	5.48	2.06
14	11.92	10.02	8.24	5.91	2.23
15	12.74	10.71	8.84	6.33	2.40
16	13.56	11.40	9.45	6.74	2.56
17	14.38	12.09	10.01	7.13	2.71
18	15.20	12.78	10.55	7.52	2.87
19	16.02	13.47	11.08	7.90	3.01
20	16.83	14.15	11.61	8.25	3.15

Cross-section of E. saligna Stems in Zululand.

A feature of *E. saligna* grown in Zululand is the marked ellipticity in stem cross-section and the fact that the major axis of the ellipse coincides with the direction of the prevailing winds. It is a reasonable assumption that the phenomenon is a physiological reaction of the tree to wind.

Figures of wind velocity, frequency and direction are to be found in the Weather Bureau publication "Surface Winds of South Africa". Figures, relating to the Durban Meteorological Station are given below.

Wind direction	Mean Annual velocity miles/hour	Relative frequency in %
NNW N	5.6	9.5
NNE NE	10.8	19.7
ENE E	7.2	6.0
ESE SE	6.6	3.2
SSE S	11.2	7.3
SSW SW	13.0	25.3
WSW W	6.4	4.3
WNW NW	5.7	4.2
Calm	—	20.5

Both frequency and velocity of the NNE—NE and SSW—SW winds are higher than are those of winds from other directions. Also since NE and SW winds blow from exactly opposite direction the effect of the wind in causing ellipticity is intensified.

An investigation of stem cross section was made in two stands, respectively 10 and 11 years old, in the plantations of the S.A. and General Investment and Trust Co. The 10 year old stand had received a light low thinning a year before the investigation and 121 observations were made in it. The 11 years old stand had not been thinned and 101 observations were made.

The deviation from the circular form can be expressed as follows:

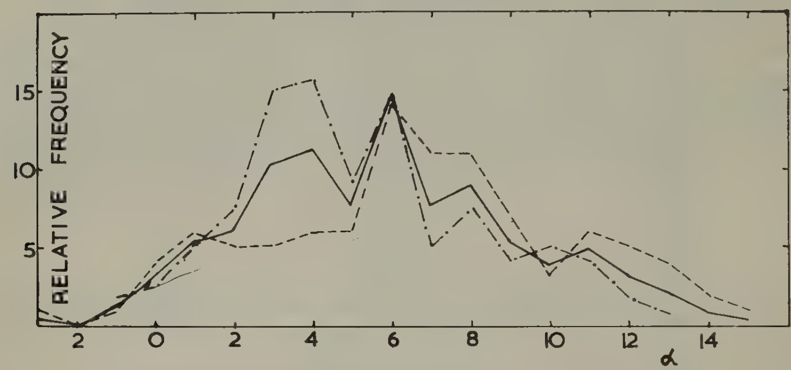
$$E = \left(\frac{D_1}{D_2} - 1\right) \times 100$$

in which E is the factor of deviation, D_1 is the maximum diameter and D_2 the diameter at a right angle to D_1. Values for E will always be positive. When the diameter was measured the angle between North and the direction of D_1 was measured by compass and a value, denoted here by α was given to each reading based on a division of the compass into 64 units as follows. North was given a fixed value of zero, East +16 and West —16. In this way every observation could be expected to have

a value between +16 and —16. If there were no influence due to a specific site factor, in this case wind, a rectangular frequency distribution of the values of α between +16 and —16 could be expected.

The actual frequency distribution of α is given in figure 6.

Figure 6.



Frequency distribution of the angle α.

The values appear to be normally distributed and all observations are located between —3 and +15. The averages are:

For 10 jaar old stand $\alpha = 5.2 \pm 0.28$
For 11 year old stand $\alpha = 6.6 \pm 0.40$

The difference between the means is small but statistically significant. The weighted average for the two plots is 6.0 and this corresponds to a direction for the major axis between NNE—SSW and NE—SW, and this in its turn coincides with the wind direction of greatest frequency in this region.

The values of E are also normally distributed and the averages are:

For 10 year old stand E = 12.18 ± 0.53
For 11 year old stand E = 10.60 ± 0.62

The difference between the two values of E is significant at the 5% level.

The possibility arises that the value of E for any individual tree might be affected by its sociological position within the stand. This sociological position or status of any tree is classified as dominant, co-dominant, dominated or suppressed and finds expression in its vigour of growth and thus in its diameter. The question can therefore be considered by correlating the factor E of any tree with diameter. The regression of the factor E on d.b.h. has been shown to be significant at the 5% level and it is positive. Thus the deviation from circular form expressed as a percentage of the diameter increases with increasing diameter.

4. *Bark Thickness and Bark Volume.*

Measurements of bark thickness, made with a Swedish bark gauge of 357 sample trees were obtained from the Department of Forestry.

Analysis shows that there is a linear relationship between diameter and bark thickness. Following are the figures:

Table 2.

Relationship between Diameter over bark, and Bark Thickness Doubled.

Diameter o.b. (inches)	Bark Thickness, Doubled (inches)
2	0.20
4	0.29
6	0.39
8	0.48
10	0.57
12	0.67
14	0.76
16	0.85
18	0.94
20	1.04

The volume of bark for each tree was correlated with diameter, over bark, at breast height. The results are set out in Table 3.

Table 3.

Bark Volume expressed as Percentage of Overbark Volume.

D.B.H. (inches)	Bark Volume (%)	D.B.H. (inches)	Bark Volume (%)
2	20.5	14	12.0
4	18.2	16	11.5
6	16.3	18	11.0
8	14.8	20	10.9
10	13.5	30	10.8
12	12.6	40	10.7

The relative bark volume decreases with increasing diameter to approximately 22 inches and remains constant thereafter. This bark volume however is dependent not only upon the diameter but apparently also on the genotype of the tree. The bark thickness of the form found frequently in the Eastern Transvaal is considerably greater than that of other known forms.

CHAPTER IV

FACTORS, AFFECTING GROWTH OF E. SALIGNA

1. *Site Indices.*

For widely accepted reasons height of the stand at a given age has been used as the indicator of site quality to express most satisfactorily the productive capacity of a given site for a given species. But in using height as the indicator, distinction must be made between mean

height and top height. The mean height of a stand is usually defined as the regression height of the tree having the mean volume and is read from the height/d.b.h. curve which is drawn for each sample plot. But, because in any site class, the mechanical act of a thinning can have the arithmetic effect of increasing mean diameter and therefore mean height, the latter is not of itself necessarily a reliable index; for this reason the use of top height, commonly defined as the arithmetic mean of the 100 highest trees per unit area is preferred. In this study top height is defined as the regression heigh of $\bar{d} + 1\frac{1}{2}s_d$ where $\bar{d}$ is the arithmetic mean diameter and s_d the standard deviation. The addition of this measure of standard deviation to the arithmetic mean diameter eliminates for the most part the systematic error due to the fact that the mean diameter after a thinning is higher than that before thinning since the standard deviation after thinning is lower than that before thinning.

In the analysis of the sample plot data plots were divided into groups comprising the sample plots in a given district; the top height of each plot was plotted against the age of the stand, a smooth curve fitted and corrected after a computation of the average deviation. Comparison of the results showed that whilst there was a difference in the level of the site index curves of different groups, e.g. between Westfalia Estate and Waterhoutboom, the trend and shape of the curves were similar. Also there were indications of superior early development of the Zululand stands, but this was thought to be due more to the method of establishment (i.e. whether from transplants or from coppice).

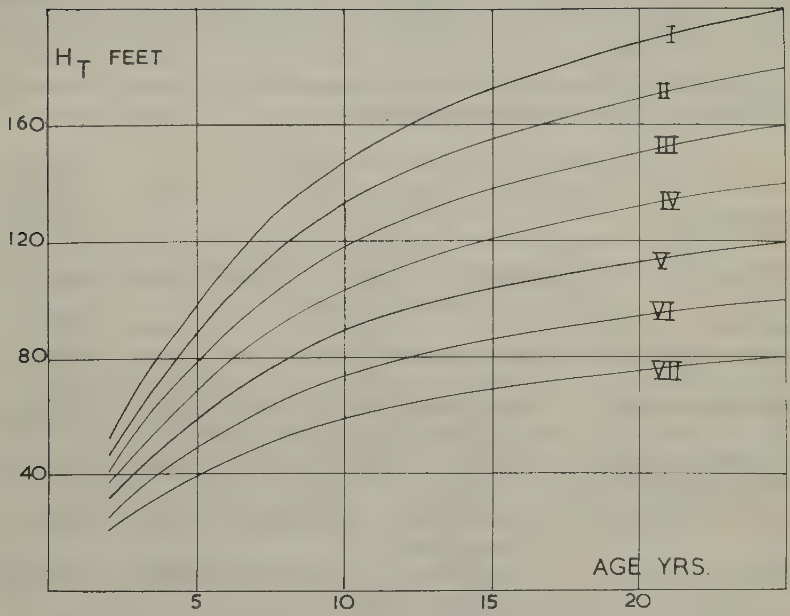
25 Years old. E. saligna stand at Broadmoor Estate, site index I.

In these circumstances it was considered justified to combine all sample plots in the construction of one single set of site index curves (Figure 7).

In this way seven site indices were established, with differences in top height of 20 feet between each class at the standard age of 25 years. These site indices are:

Site index	*Top Height at 25 years* (feet)
I	200
II	180
III	160
IV	140
V	120
VI	100
VII	80

Figure 7.



Site index curves for indices I-VII.

2. *Relation between Site and Growth.*

Whilst climate is the dominant factor influencing the growth of *E. saligna,* any conclusions may be confounded by a series of factors of which the main are:

(a) Rainfall varies over short distances with the result that the statistics of the Weather Bureau Meteorological Stations relating to a given locality are not necessarily applicable to a given plantation in the same locality. Even within a given plantation the rainfall may not be uniform and it may be

theoretically wrong to correlate the mean site index of a plantation with rainfall in specific locations within that plantation.

(b) The average rainfall during a 7—10 year period of the life of a stand may differ considerably from the weather station statistics which are the average of a longer period.

(c) The distribution of the rainfall over the months of the year, as well as the kind of precipitation is almost as important as the total rainfall. Particularly in the Transvaal, periods of drought can be disastrous for the growth of stands.

(d) Water consumption by the trees is related to rainfall, temperature and soil. Evapotranspiration requirement increases with temperature and in a district characterised by high temperatures the amount of precipitation necessary to meet the water requirement of the trees is higher than in districts with a lower mean temperature. In this connection the physical properties of the soil are important and together with the local variations in climate produce the complex set of conditions which are expressed as the site index of the stand.

The following table shows the mean site index of a number of plantations with decreasing productivity:

Plantation	Climate	Soil	Mean Site class Index
Rooikoppies	Temperate, warm humid summer rainfall	loam	3.02 ± 0.18
Westfalia	do	loam	3.29 ± 0.10
Montigny (Zululand)	Sub-tropical humid summer rainfall	sand	3.46 ± 0.10
Waterhoutboom	Temperate, warm humid summer rainfall	loam	4.07 ± 0.11
Other plantations in White River area	do	loam	4.17 ± 0.14
S.A.G.I.T. (Zululand)	Sub-tropical humid summer rainfall	sand	4.22 ± 0.09
Driekop	Temperate, cool humid summer rainfall	loam	6.07 ± 0.13

The climatic types used in the above table are those used in the Department of Forestry's division of the Union into silvicultural zones. The range of temperature and rainfall characteristics of these zones is:

	Mean annual Temperature (°F)	Mean annual Rainfall (inches)
Temperate, cool, humid summer rainfall zone	55°—62°	33″—75″
Temperate, warm humid summer rainfall zone	62°—67°	35″—75″
Sub-tropical humid summer rainfall zone	67°—73°	40″—60″

The above figures show that the growth of E. saligna in the coastal belt of Zululand is similar to that on the more fertile loamy soils of the Transvaal. The mean site index at Montigny is nearly as high as that at Westfalia. Mean annual rainfall at Westfalia over the period 1910—1945 was 54 inches, but over the period 1936—1950 it was 5 inches lower. Mean annual rainfall at Kwambonambi, the nearest meteorological station to Montigny is 51 inches. Also the rainfall in Zululand is more evenly distributed than it is in the Transvaal, where during the winter months the trees are largely dependent upon the water reserve in the soil.

Within a given region there appears to be a positive correlation between site index and precipitation. The mean site index at Rooikoppies is higher than at Westfalia; the annual rainfall is 5—10 inches higher. Also the mean site index of the sample plots at Montigny is considerably higher than that of the plantations of the S.A. & General Investment and Trust Co.; the annual rainfall at Montigny is 10 inches higher.

The reason for the inferior growth at Driekop has to be sought in other directions since the annual rainfall of 55—60 inches should be sufficient for good growth. It is probable that temperature is a limiting factor, for not only is the temperature range on the Driekop plateau considerably greater than in other *E. saligna* areas, but the absolute minima are lower. Following are the absolute minimum temperatures for Empangeni and Driekop during the months of May to August.

	Absolute minimum temperature (°C) at Empangeni	Driekop
May	3.9	—3.9
June	3.3	—5.4
July	1.1	—3.9
August	5.0	—3.7

It is probable that growth of E. saligna at Driekop ceases completely during the winter months. It seems reasonably certain that this factor of temperature has the effect of depressing the site index value for E. saligna in other moderately cold parts of the Transvaal escarpment where the species is grown.

3. *Influence of Soil Preparation on Growth.*

Investigations carried out in Zululand by Lückhoff (1955) show that growth is affected by soil preparation and that the best growth was obtained from the most intensive method of soil preparation.

Verification of Lückhoff's conclusion was obtained from measurements of sample plots in stands established on soils prepared by different methods.

(a) *Hathorn Series of Plots, Zululand.*

8 Plots were established in first generation stands which had been established on old agricultural land; 4 of these, nos. Z124, 126, 128, 130 are in stands established after complete preparation by ploughing and harrowing; the remaining 4 plots, nos. Z125, 127, 129 and 131 were in

stands in which the ground had been prepared by cultivating alternate 9 foot strips with a rotary cultivator.

Because of differences in soil fertility the observations have been paired as follows:

I: Plots 124 and 125, II: Plots 126 and 127, III: Plots 128 and 129, IV: Plots 130 and 131.

The following table gives the data for the plots:

Group	I		II		III		IV	
Sample plot	Z124	Z125	Z126	Z127	Z128	Z129	Z130	Z131
Age (years) ...	4.5	5.1	4.4	5.3	4.4	5.4	4.0	5.4
Number of stems/acre ...	524	525	494	489	476	483	494	449
d_v (inches) ...	6.38	6.34	6.42	6.36	6.37	6.50	6.17	6.46
h_v (ft.)	67	67	63	68	64	69	60	62
Site index ...	3.2	3.4	3.6	3.7	3.3	4.0	3.2	4.1
Mean annual incr. cu. ft./ acre to 3″ ...	541	479	499	433	479	453	476	377
Stocking % ...	96.7	96.7	90.9	90.9	86.8	91.7	90.9	84.3
$(S_d : d)$ 100 ...	30.8	35.0	23.6	33.5	29.3	31.5	39.0	42.8

Height and diameter in the completely cultivated plots are superior to those in the partially cultivated ones. The average site index is 3.3 for complete cultivation and 3.8 for partial cultivation and the respective average mean annual increment figures are 499 and 435 cu. feet per acre per annum.

Plots Z125, 127, 129 and 131 have a higher coefficient of variability of the diameter indicating that mortality and subsequent blanking in them was heavier than it was for the completely cultivated plots.

(b) *White River Plots.*

4 Plots were measured in the Atherstone and Brooks plantations: plots T208 and 210 were in first generation stands established in ground completely prepared by ploughing and plots T209 and 211 in first generation stands established in ground which had been prepared by pitting. Growth data are:

Sample plot	T208	T209	T210	T211
Age (years)	1.3	1.3	3.5	3.5
Site index	—	—	5.4	8.0
Stems/acre	—	—	413	468
d_v (inches)	—	—	4.3	2.6
h_v (ft.)	11	1	40	22
Mean increment cu. ft./acre/ years to 3″	—	—	118	—
$(S_d : \overline{d}) \times 100$	—	—	29.8	35.5

The results support the conclusion that growth is superior in the more intensively prepared soils.

(c) *White River:* Mr. Rottcher.

Mr. Rottcher has employed a method of establishment in which intensive soil preparation is combined with the interplanting of agricultural crops. The method aims at decreasing the cost of establishment and improving the physical and chemical properties of the soil.

The vegetation is burnt, the ground is ploughed twice and then harrowed. The planting espacement is 4—6 feet in the rows and 12—14 feet between the rows, and the method is locally referred to as "avenue planting". The newly planted stand is weeded during the first year and disc-cultivated in the second and/or third years. A complete fertiliser is applied as a surface dressing before the disc cultivation, and maize is then planted between the rows. The yield of the agricultural crop covers the costs of soil preparation completely. The sample plots T237, 239 and 241 are examples of avenue plantings, combined with intensive soil preparation. Planted stands with a different method of soil preparation could not be found on comparative sites, but the growth data of T237, 239 and 241 can be compared with the sample plot data of T236, 238 and 240, laid out in coppice stands. The soil under these stands was not cultivated when regeneration took place.

Following are the measurements of the plots:

Group	I			II		
Establishment	Planted stands			Coppice		
Sample plots	T237	T239	T241	T236	T238	T240
Age (years)	5	4	3	7	$6\frac{1}{2}$	7
Site index	3.4	4.0	4.0	6.0	5.9	4.9
Stems/acre	506	399	856	739	463	458
d_v (inches)	5.76	5.17	3.70	4.32	4.70	6.23
h_v (feet)	67	52	44	55	52	66
Mean increment cu. ft./ acre/annum to 3 inch	376	228	200	148	121	287

The mean site index of the planted stands is 3.8, that of the coppice 5.6. The mean annual increment of the planted stands is 268 cu. ft. per annum that of coppice 185 cu. ft. per annum. When these figures are converted to the age of 5.5 years for both groups of stands, they are resp. 370 and 157 cu. ft. per annum. It is possible that the inferior growth in stands T236, 238 and 240 is due in part to a strong invasion of grasses and other vegetation after the regeneration of the stands.

The sample plots T243 and 244 are second rotation stands on agricultural land. The soil in plot T243 was ploughed and interplanted

with maize after the establishment of the stand. In T244 pit-planting had been carried out. The sample plot data were:

Sample plot	T243	T244
Age (years)	1.5	1.5
Stems/acre	781	813
d_v (inches)	2.5	2.5
h_v (feet)	29.5	29.5
Mean increment cu. ft./acre/ annum to 3″ ...	174	181

In this case the intensive soil cultivation has not resulted in improved growth.

These figures together do not solve the problem of soil preparation completely, but they support the general idea based on practical experience that intensive soil preparation gives good results in stands which are first generation forest on old agricultural land. Soil preparation is less effective in stands of second or third generation. The problem is further complicated since both in planted and coppice stands the physical and chemical properties of the soil and the presence or absence of soil vegetation has to be considered.

4. *The growth of Planted Stands Compared with Coppice Stands.*

In coppice stands the immediate availability of a well-developed root system for the transportation of water and nutrients favours the rapid early growth of the crop.

Against this in planted stands the young plants have to develop an adequate root system and particularly during the first year they are highly susceptible to the effects of drought. It is thus inevitable that in the first year after establishment the growth of planted stands should be slower than that of coppice regrowth.

To obtain a comparison between the growth of planted and coppice stands of different ages, site index determinations have been made for stands of different age classes in the Northern and Eastern Transvaal and in Zululand. The data are given below.

Region	N. Transvaal					
Age Class	I		II		III	
	2.0—3.5 yrs.		3.6—7.0 yrs.		7.1—13.0 yrs.	
Establishment	P	C	P	C	P	C
Number of sample plots	5	5	21	20	4	12
Mean site index	2.78	2.38	3.07	3.31	3.65	3.67
Standard error	—	—	0.147	0.155	—	—

Region	E. Transvaal					
Age Class	I		II		III	
	2.0—3.5 yrs.		3.6—7.0 yrs.		7.1—13.0 yrs.	
Establishment	P	C	P	C	P	C
Number of sample plots	3	—	8	11	11	11
Mean site index	5.3	—	4.27	4.37	4.01	4.32
Standard error	—	—	0.418	0.259	0.319	0.164

Second generation E. saligna coppice stand at Kwambonambi, 12 years old, site index III.

Region	Zululand					
Plantation	Saligna Forestry Company					
Age Class	I		II		III	
	2.0—3.5 yrs.		3.6—7.0 yrs.		7.1—13.0 yrs.	
Establishment	P	C	P	C	P	C
Number of sample plots	24	71	69	94	41	90
Mean site index	6.72	5.77	6.10	5.57	5.70	5.25
Standard error	0.166	0.115	0.100	0.083	0.103	0.067
Difference	0.95		0.53		0.45	
Standard error of difference	0.220		0.129		0.122	

Region	Zululand					
Plantations	Gen. Investm. and Trust Co.					
Age Class	I		II		III	
	2.0—3.5 yrs.		3.6—7.0 yrs.		7.1—13.0 yrs.	
Establishment	P	C	P	C	P	C
Number of sample plots	2	5	17	12	17	49
Mean site index	2.80	2.16	4.58	3.66	4.56	4.35
Standard error	—	—	0.165	0.165	0.143	0.095
Difference	—		0.92		0.21	
Standard error of difference	—		0.240		0.182	

The figures indicate:

(i) Apart from slightly superior growth in coppice stands during the first year there is no difference between the height growth of planted and coppice stands in Transvaal plantations.

(ii) In the case of Zululand plantations the difference in site index is significant up to the age of 7 years in the plantations of the General Investment and Trust Co. and up to the age of 13 years in the plantations of the Saligna Forestry Company.

There are indications, however, that part of the difference in favour of the coppice stands may be correlated with soil fertility and that the superiority of the rate of coppice growth may be smaller when soil fertility, and consequently production level, is higher.

5. *The Growth of Successive Generations of Coppice.*

It is common practice to grow successive generations of coppice from the original stools and to regenerate by planting after two, three or more coppice crops have been harvested. The method is convenient and regeneration costs are lower than with replanting. At the same time it is of economic importance to know whether, and if so at what point,

production may decrease with an increasing number of coppice generations. There is much uncertainty on the matter.

Investigation of the problem has been difficult, because there are very few areas in South Africa where different coppice generations on comparable sites are available.

Only in a small district in the Northern Transvaal could an investigation be made and 26 sample plots were measured. Of these 4 were in planted stand, 10 in second generation coppice, 7 in third generation coppice and 5 in fourth generation or older. Group means for site index and percentage stocking were:

First generation coppice stand.

C

Group	*Mean site index*	*Mean stocking %*
I planted stands	2.90	84.2
II coppice, 2nd generation ...	3.61	74.8
III coppice, 3rd generation ...	3.40	74.9
IV coppice, 4th generation ...	3.18	59.6

An analysis of variance showed that the difference between the mean site index of the groups is not due to the method of regeneration or number of coppice generations. A second analysis showed that the manner of establishment has a significant effect on the percentage stocking, differences being significant at the 1% level. In other words: the height growth, and consequently the site class, does not change with an increasing number of coppice generations, but the number of stems per acre decreases, because an increasing number of stools dies. A decreasing volume yield can therefore be expected but the rate of decrease depends upon the original espacement. Usually this is 9 x 9 ft., corresponding to 538 trees per acre. If the number of trees per acre is decreased to 320, the expected volume production will be 14% lower than the volume yield of the original planted stand. In reality, however, the production loss will be greater, because the trees are often felled carelessly so that stump height increases with every generation. This loss of production can be avoided by improved felling technique.

There remains the possibility of leaving two shoots per stool instead of one, to compensate for the loss in volume production due to the decreasing number of stools. In this connection it was necessary to determine whether diameter increment of individual stems was influenced by the number of stems per stool. 9 Stands in the N. Transvaal in which the number of stems per stool had been reduced to 2 were examined. The reduction had not been consistent and individual stools with only one stem were found. The trees in the stand were therefore divided into the groups viz., those with one and those with two stems per stool. The arithmetic mean diameter in each group was calculated and the results were:

Sample plot	Mean diameter $\bar{d}_1$ of trees with one shoot per stool (inches)	Mean diameter $\bar{d}_2$ of trees with two shoot per stool (inches)	$\bar{d}_2 - \bar{d}_1$
T65	4.22	4.42	+0.20
T67	4.80	4.65	—0.15
T68	4.51	4.18	—0.33
T73	3.01	3.22	+0.21
T88	4.43	4.63	+0.20
T91	4.27	4.67	+0.40
T92	4.21	4.71	+0.50
T97	5.77	5.93	+0.16
T98	5.95	6.12	+0.17

Increased stump height in third or fourth generation coppice.

The average of the individual differences $\bar{d}_2 - \bar{d}_1$ is 0.15 ± 0.084. This difference is not statistically significant and the following conclusion can be drawn:

The diameter growth of the individual stems is not influenced by the number of stems per stool provided that the number is not greater than 2.

Jacobs (1955) found in Australia that new coppice generation does not develop new main roots, but daughter roots of higher order may be formed repeatedly. The roots of higher order and the root hairs

are more important for the supply of water and mineral nutrients than is the main root system. It is possible therefore that each individual stem on a stool develops a system of root hairs.

The leaving of two shoots per stool instead of one will compensate for the loss in volume production due to the decreasing number of stools, but clearly this system cannot be applied in all circumstances. It cannot be recommended for saw timber plantations because these have to be thinned regularly in order to give adequate space to the individual trees. It can be recommended however for stands producing pulpwood and mining timber. The lower portions of the stems in stands thus treated are inclined to lean outward; this is not very important for pulpwood and mining timber.

6. *Influence of Vertical Mixture on the Growth of Coppice in Coppice with Standards.*

The coppice with standards system has been used only at Westfalia Estate in N. Transvaal. The original idea was to combine the production of sawtimber in long rotation with the production of mining timber in short rotation, in order to improve the financial results of the undertaking. The planted stands were heavily thinned at the age of 6—9 years, and the number of stems per acre reduced to 27—70. This silvicultural system has not given satisfactory results and is no longer applied.

An analysis of the sample plot data of a number of these stands, derived from the working plan 1953—1958, gives the following result:

The mean site index of the standards is 4.30, of the coppice 5.00, so that the difference in site index is 0.70. The influence is probably one-sided, the height growth of the coppice being retarded by lack of light, and perhaps also by root competition. It is possible also that the growth of the standards was retarded as a consequence of root competition with the coppice but the effect would be slight.

There is also a relation between stand density of the standards and the growth of the coppice. The stand density can be expressed by the stand density index of the stand (S%) i.e. the ratio $\dfrac{\text{mean distance between the trees.}}{\text{top height of the stand.}}$ This index is discussed further in chapter V. The top height at the time of the conversion felling can be estimated from the yield table. Since the number of stems per acre has not changed the S% at that time can also be calculated. This stand density index has been correlated with the difference in site index between standards and coppice. An analysis of variance showed that the regression is highly significant. The regression coefficient, designating the regression of difference in site index on S% has a negative value, indicating that the influence of the standards on the height growth of the coppice decreases as the S% of the standards rises. When the S% of the standards, at the time of regeneration is 58, the difference in site class is 0 ± 0.227.

This means that a heavy conversion felling is necessary to avoid this competition with its consequent retarding of coppice growth. An S% of 58 corresponds, in site class IV, age 7 years, to 17 trees per acre.

The height-diameter ratio of the coppice is also influenced by the standards. An analysis of the regression of mean height on mean

diameter in these stands showed that the mean diameter of a stand with a mean height of 76 feet is 5.65 ± 0.14. The mean diameter, corresponding to a mean height of 76 ft. in even-aged stands should be 6.50 inches. In the first case the height diameter quotient is 161 and in the second case 140.

The silvicultural system "coppice with standards" cannot be recommended for practical application. The coppice shows all the symptoms of suppression: small crowns, dark leaves, inferior height growth and greater height/diameter ratio.

7. *Influence of Espacement on the Growth of Unthinned stands.*

The influence of espacement on volume yield and mean diameter was studied separately in Zululand and in the Transvaal. Since there is a functional relation between planting distance and number of stems per acre, it is permissible to correlate the volume yield with the number of stems per acre. There is a strong correlation between top height and volume yield and in order to eliminate the influence of the top height the sample plots have to be grouped according to top height classes. Computations were made for the top height classes 30—40, 40—50, 60—70 and 95—105 feet in Zululand and 65—75, 75—85 and 85—95 feet in the Transvaal. The number of observations in the other classes was not sufficient for statistical investigation. Since it was necessary to make the height classes 10 feet, the volume yield of each sample plot had to be corrected for the yield at the mid-point of the class. It was also necessary to adjust the volume yield of each sample plot to bring it into line with that of the average site index, which for this investigation was assumed to be IV.

The analysis of regression completed for the above-mentioned height classes in Zululand gave the following results:

1. The yield of merchantable volume (to 3″) in the height class 30—40 feet decreases with increasing number of stems per acre.
2. In height class 40—50 feet, there is no correlation between number of stems per acre and volume yield.
3. The volume yield in height classes 60—70 and 95—105 feet increases with increasing number of stems per acre.

The relation between volume yield and number of stems can be expressed by the equation $Y = a_o + a_1 X_1$ where

X = number of stems per acre.

Y = volume cu. ft./acre (to 3″).

a_o and a_1 = constants of the equation.

The result of the computations are:

	Number of Stands	a_o	a_1	S_{a1}	$t = \frac{a_1}{S_{a1}}$	t+	t++ (1)
I h_{dom} 30—40′	70	258.3	—0.1840	0.0484	3.80	1.99	2.65
II h_{dom} 40—50′	93	415.2	0.0976	0.0613	1.59	1.99	2.63
III h_{dom} 60—70′	112	1003.9	1.0966	0.2295	4.78	1.98	2.63
IV h_{dom} 95—105′	61	3467.1	1.4531	0.7460	1.95	2.00	2.66

(1) t+ and t++ denote the t-values for which the regression is significant with a probability of 95%, resp. 99%.
The result of this test is given above.

The result is different when the merchantable stem volume to a top diameter of 3 inches is replaced by total stem volume. A computation of the regression equation, based upon total stem volume, results in the conclusion that the volume yield in all height classes increases with increasing number of stems per acre. This discrepancy in the results is caused by the influence of the number of stems on the mean diameter of the stand. When the number of stems per acre is higher, the yield, expressed in terms of total stem volume, is higher, but the mean diameter and corresponding utilisation percentage are lower. The influence of the utilisation percentage is dominant while the stands are young and the top height is not more than 40 feet, as a small difference in diameter results in a great difference in utilisation percentage. As the stands mature, the influence of mean diameter on utilisation percentage decreases.

The number of observations in the Transvaal is considerably smaller and the result less reliable. The conclusion that the volume yield increases with increasing number of stems seems to be justified for the Transvaal as well, but the conclusion is only weakly confirmed by statistical tests.

The result of the test of significance is given below.

	Number of Stands	a_0	a_1	S_{a1}	$t=\frac{a_1}{S_{a1}}$	t+	t++
I h_{dom} 65—75′	45	1271.8	0.654	0.441	1.48	2.02	2.70
II h_{dom} 75—85′	34	1793.5	0.852	0.425	2.00	2.04	2.75
III h_{dom} 85—95′	32	2120.6	1.557	1.150	1.35	2.04	2.75

There are indications that the volume yield increases with increasing number of stems, but in the groups I and III the t-values calculated lie considerably below the 5% level of significance.

The question arises as to whether the relation between number of stems and volume yield is also influenced by the site index. The opinion has sometimes been expressed that the number of trees should be less on infertile sandy soils since the quantity of water and nutrients available in these soils is smaller. To verify this, the sample plots in the Transvaal and in Zululand were divided into two groups, consisting of the stands with a site index above and below IV. The volume yield of the stands was plotted against top height and fitted graphically. The result does not give any indication that it might be justifiable to apply a wider espacement on poorer sites. The problem is probably much more complicated, because the growth of the stand is not only dependent on the water consumption of the young trees, but also upon the water consumption of the competing soil vegetation. The crown canopy closes later when the trees are planted at wider spacings and a greater length of time elapses before grasses and other weeds are suppressed. It is reasonable to assume that the total water consumption of trees and soil

vegetation together is approximately the same in stands of different spacings.

The result of the calculations is given in table 4. The stocking percentage in Zululand is fixed at 80% and in Transvaal at 85%.

Table 4.

Volume Yield of Stands with Varying Planting Distances.

Zululand

Espacement	Stems/acre	Volume yield cu. ft./acre site index IV $h_{dom} = 100$ ft. Age appr. 9 yrs.	Volume yield as % of yield of 9 x 9 ft.
7 x 7 ft.	711	4500	110.0
8 x 8 ft.	544	4258	104.0
9 x 9 ft.	430	4092	100.0
10 x 10 ft.	349	3974	97.1
11 x 11 ft.	288	3886	95.0
12 x 12 ft.	242	3819	93.3

Transvaal
(Site index IV, $h_{dom} = 80$ ft., age approx. 6 years)

7 x 7 ft.	756	2438	111.6
8 x 8 ft.	579	2287	104.7
9 x 9 ft.	458	2184	100.0
10 x 10 ft.	371	2110	96.6
11 x 11 ft.	306	2054	94.0
12 x 12 ft.	258	2013	92.2

The mean height of the stand can be derived from the top height and the mean volume of the trees from total volume and corresponding number of stems. When mean height and mean volume are known, the mean diameter can be derived from the alinement chart. The result is given in table 5.

Table 5

Mean Diameter of the Stand with Varying Number of Stems per Acre

Region	Zululand				Transvaal
Top height in feet	35	45	65	100	80
Number of stems per acre	Mean Diameter (Inches)				
250	4·39	5·26	7·09	9·38	7·87
350	3·84	4·66	6·26	8·22	6·80
450	3·55	4·30	5·77	7·51	6·25
550	3·34	4·08	5·44	6·96	5·81
650	3·20	3·89	5·21	—	5·50

CHAPTER V

THINNING AND PRUNING IN SALIGNA STANDS

1. *Thinning.*

(i) *The Development of the Crown.*

As soon as the canopy has closed, the width of the crown is entirely dependent on the distance between the trees. The width increases with increasing distance between the trees, and the total assimilating surface of leaves per tree also increases. This results in an increased volume production of the individual tree. There is also a relationship between the distance between the trees and the relative length of the living crown. The lowest branches die off as soon as the canopy closes and the bottom of the living crown gradually moves upwards.

The effect of thinning on crown dimensions was studied in 39 stands at Westfalia of differing age and site class. In each stand the crown width of 15 trees, uniformly distributed over all diameter classes was measured, by measuring the crown projection on the ground in two directions at right angles. In addition the crown length of 3,780 trees in 252 stands in the Transvaal and Zululand was measured. Height measurements were also made.

A preliminary graphical examination showed that a linear relation exists between crown width and stem diameter at breast height. A regression line for each stand was computed separately and the constants of this regression line were correlated with the age of the stand. There were indications of a correlation between the level of the regression line and the age, but this was not confirmed by the significance test. It was thus permissible to group all observations irrespective of the age of the trees. The result of the computations is given in table 6.

Table 6.

Ratio $\dfrac{\textit{Crown width}}{\textit{Stem diameter}}$ *in Crown Width Classes.*

Crown width (feet)	d.b.h. (inch)	ratio $\dfrac{\text{crown width}}{\text{d.b.h.}}$
5	2.63	22.8
10	5.52	21.7
15	8.42	21.4
20	11.31	21.2
25	14.20	21.1
30	17.10	21.0
35	20.00	21.0
40	22.88	21.0
45	25.78	20.9

Crown length is expressed as a percentage of total tree height, and the average relative crown length of a sample plot is defined as the arithmetic average of the single observations. The mean relative crown length was correlated with the stand density index and the reciprocal value of its age.

After a preliminary graphical test, the following equation has been chosen:

$Y = a_o + a_1X_1 + a_2X_2$ in which

X_1 = reciprocal value of the age

X_2 = spacing index (S%)

a_o a_1 a_2 = constants of the equation

Y = relative crown length.

The results are:

$a_o = 11.84216$

$a_1 = 74.65205$	$S_{a1} = 5.275$	$t = 14.2$	$t^* = 1.97$	$t^{**} = 2.60$
$a_2 = 2.30325$	$S_{a2} = 0.110$	$t = 20.9$	$t^* = 1.97$	$t^{**} = 2.60$

Both factors contribute significantly to the regression and the computations result in a regression equation, giving the relative crown length as a function of age and S%.

The relative crown length decreases with increasing age if the S% remains constant. It is necessary therefore to increase the S% with increasing age, in order to maintain given relative crown length. If it is desired to aim at a constant relative crown length of 50%, the S% should be 18.7% at 4 years, 22.8% at 8 years and 24.5% at 14 years.

There is a linear relation between crown width and crown length. For each group of observations, a regression equation was computed with crown length as dependent variable and crown width as independent variable. The constants of the regression equation were correlated with age and S%. The significance test showed that both factors gave a significant contribution to the regression. The ratio crown length over crown width increases with increasing age and, at a given age, with increasing S%. In other words: when the stands get older and when they are thinned, the crown becomes more slender in shape.

Following is the basis for this conclusion:

The relation between crown width and crown length, within a particular stand, can be expressed by the equation.

$Y = a_o + a_1 X$ in which

X = crown width

Y = crown length

a_o and a_1 = constants of the equation.

The value of the constants a_o and a_1 was correlated with age and S%. The following equation have been computed:

$Y_1 = b_o + b_1 X_1 + b_2 X_2$ and

$Y_2 = c_o + c_1 X_1 + c_2 X_2$

where:

X_1 = age

X_2 = S%

$Y_1 = a_o$

$Y_2 = a_1$

b_o b_1 and b_2 = constants of the first equation.

c_o c_1 and c_2 = constants of the second equation.

The results are:

b_o = —28.7133	S_{bo} = 10.090			
b_1 = 1.3024	S_{b1} = 0.341	t = 3.82	t* = 2.06	t** = 2.80
b_2 = 1.8390	S_{b2} = 0.580	t = 3.17	t* = 2.06	t** = 2.80
c_o = 3.7422	S_{co} = 0.800			
c_1 = 0.0394	S_{c1} = 0.027	t = 1.46	t* = 2.06	t** = 2.80
c_2 = 0.1089	S_{c2} = 0.046	t = 2.37	t* = 2.06	t** = 2.80

(ii) *A tentative Thinning Scheme for Sawtimber Stands.*

In defining thinning treatments, research workers in most European countries have followed the recommendations of the International Union of Forest Research Organisations. The thinning grade is based on a biological classification and commonly consists of two types, viz. thinning from below and thinning from above. The trees are classified according to their biological position in the stand, as dominant, co-dominant, dominated and overtopped, and the thinning grades are designated according to the various tree classes which are removed. This definition has caused difficulty, because it specifies the tree classes, but not the number of trees in these classes, which have to be removed nor the interval between one thinning and the next. Attention is concentrated, moreover, on the trees removed rather than on the trees which are left. Investigations based on tree class methods are also troublesome when the results of experiments in different countries have to be compared. Investigators in England and Holland have changed to other methods.

Satisfactory results have been obtained with Hart-Becking's stand density index, based on number of stems per unit area and top height (Becking 1953). This index (S%) is defined as the average spacing between the trees, expressed as a percentage of the top height, i.e. the arithmetic average of the 100 highest trees per unit area, in Great Britain the acre, in Holland, the hectare. The mean distance between the trees is derived from the number of stems per acre. If square spacing is assumed, the following relation exists between the number of stems per acre (N) and the planting distance (a).

$$N = \left(\frac{209}{a}\right)^2$$

For convenience a table has been constructed, to give values for N in terms of a range of values for a.

Table 7.

Relation between Number of Stems per Acre and Mean Distance between the Trees.

a	N	a	N
9	538	26	64
10	436	27	60
11	360	28	56
12	303	29	52
13	258	30	48
14	222	31	45
15	194	32	42
16	170	33	40
17	151	34	38
18	134	35	36
19	121	36	34
20	109	37	32
21	99	38	30
22	90	39	28
23	82	40	27
24	76	41	26
25	70	42	25

In developing a tentative thinning scheme, three factors have to be considered:

1. Age at first thinning.
2. Relation between age and S% of the remaining stand.
3. Interval between successive treatments.

The average S% of stands on Westfalia Estate at the time of first thinning is 12.5. The relative crown length is 35—36% and some time elapses before the crowns respond to the thinning. Such setbacks should be obviated in the production of sawtimber and the thinning should aim at improving vigour of growth and stem quality of the individual trees of the final stand. Wind damage, which occurs frequently in these dense stands, particularly on exposed sites, could be avoided if the first thinning were made earlier. It would be preferable therefore, to make an earlier first thinning, for example as soon as the S% of the stand is 16.

Closely spaced stands have to be thinned earlier than widely spaced stands. It is not exceptional to find that an espacement other than 9′ has been adopted in stands planted to produce sawtimber and it is of interest to examine briefly the implications of this. Assuming that a first thinning is done when S% is 16, and espacement of 7′ and 80% stocking the top height at the first thinning is 48.7 feet, regardless of site index. At this point stand volume for the different espacements will be:

Espacement	Volume cu. ft./acre to 3″ (h_{dom} = 48.7′)
7 x 7′	724
8 x 8′	677
9 x 9′	645
10 x 10′	623
11 x 11′	605
12 x 12′	593

The volume per acre, at a 7 x 7′ espacement is only 79 cu. ft. (i.e. 12%) higher than that of a 9 x 9′ espacement. According to the yield table for Zululand, the total volume at 15 years is 6,360 cu. ft./acre so that the difference of 79 cu. ft., corresponds to 1.2% of the total production. The mean diameter of the stand at the time of the first thinning is 4.0 inches, that of the removed trees is estimated at 2.5 inches and of the volume removed only 7—10% is utilisable for mining timber of pulpwood. The market value of the first thinning is therefore negligible.

A stand with a higher number of stems allows a wider selection of trees of good quality and growth vigour, but there are sufficient trees for effective selection in stands planted at 8 x 8′ and 9 x 9′. An espacement of 7 x 7′ cannot therefore be recommended for the production of sawtimber. In stands with wider spacings, ranging from 10 x 10′ to 12 x 12′, there is a small loss in production at this age which financially, is compensated by the lower costs of planting and felling. The main objection to these wider espacements, however, is the inadequacy of the material available for selection and for this reason they cannot be recommended. If the stand is not regenerated by coppicing, but by replanting, an espacement of 9 x 9′ is recommended, but when one or two generations coppice are grown from the original stools, an espacement of 8 x 8′ is preferable.

If the S% of the remaining stand is increased from 16 to 19, the mean diameter of trees removed in the first thinning in site classes III and IV can be estimated as 4.0 and 3.8 inches. The utilisation percent of the trees is respectively 63% and 59% and the volume per acre (to 3″) removed will be 174 and 134 cubic feet respectively. The average relative crown length is 43—44% so that a fall in production need not be feared. The age at the time of first thinning is dependent on site class and number of stems per acre. If spacing is 9 x 9′, and the stocking percentage 85, the first thinning in the site classes II, III, IV and V is carried out at the ages of 2.9, 3.5, 4.2 and 5.3 years. An earlier first thinning cannot be recommended. If the first thinning in site class IV were carried out at 3 years, the mean diameter of the removed trees would be 2.9 inch and the corresponding percentage of utilisable wood would be 22. By postponing the thinning for one year, the utilisation percentage increases to 59. An earlier thinning is not necessary silviculturally and is not economically justifiable.

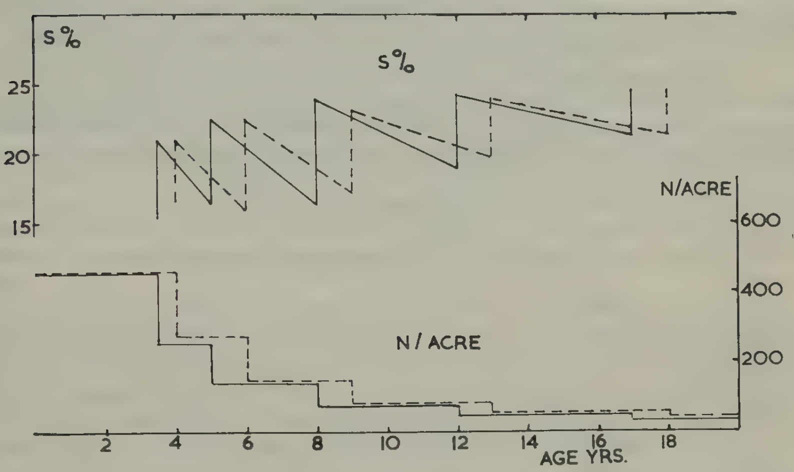
The analysis of crown dimensions showed that it was necessary to increase S% with increasing age in order to maintain a given crown length. A relative crown length of 50% at 14 years requires S% of 24.5,

and bearing this in mind, a thinning scheme can be developed for site classes III and IV.

Site class III. If the number of trees per acre is 455, the S% of the stand at 3.5 years is 15.9. With the first thinning S% is raised to 21.0, corresponding to a decrease in number of stems from 455 to 258 per acre. S% at 5 years is 16.4, and a second thinning is carried out. Because of the increasing need for light, S% increases to 22 as the number of stems is reduced to 144 per acre. The third thinning follows at 8 years, when S% is increased to 22.9 and the number of stems is reduced to 74. The fourth thinning is completed at 12 years, S% rising to 24.2 and the number of stems decreasing to 46. The last thinning follows at 17 years, the stand being thinned to S% of 24.5 and the number of stems per acre reduced to 35.

When this system is adapted for site class IV, the number of stems is greater, because the trees grow more slowly. The thinning scheme is given in table 8 and fig. 8.

Figure 8.



Thinning scheme for site indices III and IV.

Table 8.

S% and Number of Stems per Acre in accordance with the Tentative Thinning Scheme.

Site class III			Site class IV		
Age	S% (after thinning)	Stems/acre	Age	S% (after thinning)	Stems/acre
3½	21.0	258	4	21.0	278
5	22.0	144	6	22.0	147
8	22.9	74	9	23.1	84
12	24.2	46	13	23.9	58
17	24.5	35	18	24.5	44

This thinning scheme is recommended for the production of heavy sawtimber, produced on a rotation of 20—25 years. If sawtimber af smaller dimensions is produced on a rotation of 12—14 years, the number of thinnings can be reduced to 3.

2. *Pruning.*

Two factors are important in the preparation of a pruning plan:

(i) The quality of the timber required.

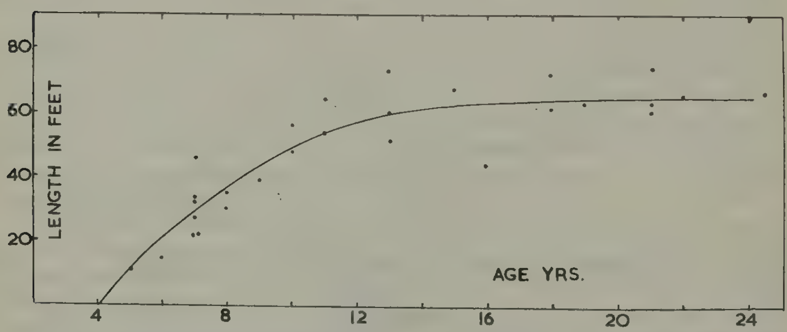
(ii) The character of natural pruning of the species.

Knots are not a serious defect in mining timber and pulpwood, but they are not permissible in timber used for furniture, and the value of the timber used for floors and boxes is correlated with the number of knots.

In E. saligna stands branches fall easily as soon as they have died and the shedding occurs in three phases (Jacobs 1955). The first phase is the development of a brittle zone near the base of the branch; the second follows in which the main part of the branch breaks away by a fracture across the outer part of the brittle zone; in the third phase a further fracture occurs, and a part of the remaining stub is ejected.

In an investigation of branch shedding, the length of the clean stem of 364 trees on Westfalia Estate, distributed over 28 stands, was measured. The mean length of the clean stem in each stand was plotted against the age (fig. 9). The figure shows that the length of the clean

Figure 9.



Relation between age and mean length of clean stem.

stem increases quickly, especially in youth, but it increases slowly after 13 years. In other words: branch shedding is very effective up to the age of 13 years. It is affected not only by physiological factors, but also mechanically by the felling of trees, removed in thinning. When these latter are felled, they scrape along the stems of the standing trees and the dead branches break off. For this reason the mean length of clean stem in unthinned stands is less than in thinned stands of the same age.

It is necessary in a pruning plan to consider both the financial aspects of pruning and the width of the knot-free timber which will be obtained as a result of pruning. The direct costs of pruning can be reduced by pruning only selected trees, namely the final crop trees, which exhibit the best stem form and superior growth vigour. But the selection

of these final crop trees should be undertaken by a skilled and experienced employee whose wages are a multiple of those of a labourer and this makes the operation relatively expensive. Also a reliable appraisal during youth of the future development of the trees can be speculative. In the circumstances it is considered preferable to prune all the trees in the stand.

Because labour costs increase alarmingly with increasing height of pruning there are definite practical height limits for this operation.

The following pruning plan based on the foregoing considerations is proposed:

(i) Prune to half the tree height immediately after the first thinning.

(ii) Immediately after the second thinning extend the pruning to half the tree height.

In the case of site index III in Transvaal plantations the first thinning should be done at the age of 3.5 years and extend to a height of 28 feet. The second pruning should be done at the age of 5 years and should extend the first pruning height to 38 feet.

In the case of site index IV plantations both prunings are made at a greater age but the height of pruning is the same.

The width of the knot-free band of wood obtained from this pruning regime is the criterion of its effectiveness.

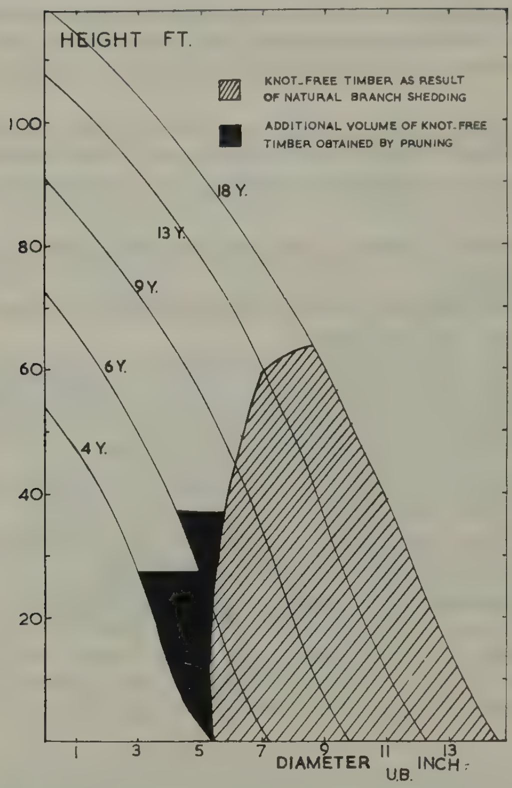
Figure 10, based on the results of the stem form data (Chapter III) and assuming the thinning regime of the Yield Table for heavy thinning, gives the stem form of a tree having the mean volume of a site index IV stand at the age of 4, 6, 9, 13 and 18 years. The figure also shows the effect of natural branch shedding and of pruning on the length of clean stem.

At the age of 18 years the under bark diameter at 5′ (i.e. the middle of the 0—10′ section of the stem) is 14.1 inches. The diameter of the inner knotty core is 5.4 inches with no pruning and 4.7 inches of the tree is pruned and the width of knot-free timber are 4.35 inches and 4.7 inches respectively. The computations have also been made for the upper sections of the stem and the results are as follows:

Stemportion	Diameter u.b. at Midpoint of Stemportion at 18 yrs. (inches)	Width of the knot-free band With pruning	Without pruning
0—10′	14.1	4.70	4.35
10—20′	13.0	4.55	3.80
20—27′	12.3	4.50	3.40
27—37′	11.6	3.50	2.95
37—50′	10.7	2.25	2.25
50—60′	9.7	1.50	1.50
60—64′	9.0	0.75	0.75
64—88′	7.2	0	0

From these figures and assuming a minimum top diameter of 5.5 inches for sawlogs the respective volumes of knot-free and knotty timber can be calculated. On a rotation of 18 years the percentage of knot-free

Figure 10.



Influence of pruning on the volume of knot-free timber.

timber is 65 with no pruning and 69.5 with pruning. In this case the effect of pruning on the quality of the timber is not great. If, however, either as a result of lighter thinning or a shorter rotation the mean diameter of the stand is less than 15.7″ the position changes. For example if the rotation is fixed at 13 years the percentage of knot-free timber is 56.6 with no pruning and 64.1 with pruning.

Estimated pruning costs are R0.00175 per tree for first pruning and R0.00800 per tree for second pruning. This corresponds with R2 per acre for first pruning and R1.60 per acre for second pruning, and includes supervision. The total costs at compound interest to the age of 12 years in site class III are R5.68 per acre (rate of interest 6%), i.e. 0.166c per cu. ft. For site class IV, the cost is 0.20c per cu. ft. at 13 years. This represents approximately 1.8% of the gross value of the sawtimber. It is therefore difficult to decide whether it is profitable to prune *E. saligna* stands producing sawtimber, and such decision must depend on the influence of pruning on the timber price per cu. ft., on rotation and on thinning regime. It is, however, reasonable to conclude that pruning can be recommended for plantations producing sawtimber which are managed on a relatively short rotation of 12—15 years.

CHAPTER VI

VOLUME YIELD OF SALIGNA STANDS

1. *Volume Yield of Unthinned Stands.*

The construction of the yield tables for unthinned stands is based on the method of Eichhorn. With this method, volume production has to be considered as a function of height, independent of the age of the stand. It has been necessary to modify the method, because the curves of volume production over height diverge with increasing age. A stand of a given top height but of lower site index will give a higher volume yield than stands of the same height of a higher site index. In other words, if top height is constant older stands have a higher volume production than younger ones. Also, it has been found desirable to construct separate yield tables for the Transvaal and Zululand.

The yield tables are based on 445 stems per acre, corresponding to the mean number of stems in the sample plots. The results are given in table 9 and 10.

Table 9.

Volume Yield Table for Unthinned Stands in the Transvaal.

Site index II.

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
3	62.5	55.6	4.68	51.0	820		273
						790	
4	76.4	68.3	5.63	74.2	1610		402
						850	
5	89.0	79.7	6.34	94.5	2460		492
						920	
6	100.4	90.1	6.85	110.6	3380		563
						900	
7	110.5	99.2	7.29	125.5	4280		613
						810	
8	119.0	107.0	7.56	135.1	5090		636
						760	
9	127.0	114.2	7.81	144.3	5850		650

Site index III.

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
3	55.6	49.4	4.49	46.8	630		210
						590	
4	67.9	60.6	5.31	65.9	1220		305
						665	
5	79.2	70.8	5.95	83.1	1885		377
						700	
6	89.3	80.0	6.45	97.9	2585		431
						700	
7	98.2	88.1	6.84	110.3	3285		469
						670	

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
8	106.0	95.2	7.15	120.6	3955		494
						625	
9	113.0	101.5	7.41	129.7	4580		509
						570	
10	118.0	106.1	7.62	137.3	5150		515
						495	
11	124.0	111.5	7.79	143.6	5645		513
						425	
12	128.0	115.2	7.92	148.5	6070		506

Site index IV.

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
3	48.6	43.0	4.21	41.0	460		153
						410	
4	59.4	52.8	4.93	56.6	870		218
						520	
5	69.3	61.8	5.54	71.8	1390		276
						550	
6	78.1	69.8	6.04	85.7	1940		323
						540	
7	86.0	77.0	6.44	97.5	2480		354
						510	
8	92.8	83.2	6.76	107.6	2990		374
						480	
9	98.7	88.5	7.01	115.9	3470		386
						440	
10	104.0	93.3	7.21	122.7	3910		391
						400	
11	108.0	97.0	7.37	127.8	4310		392
						360	
12	112.0	100.6	7.50	132.9	4670		389
						330	
13	115.0	103.3	7.61	136.9	5000		385
						310	
14	118.0	106.1	7.70	140.2	5310		379
						270	
15	121.0	108.8	7.77	142.8	5580		372
						230	
16	123.0	110.6	7.83	145.1	5810		363
						200	
17	126.0	113.3	7.88	146.9	6010		354
						170	
18	128.0	115.2	7.92	148.4	6180		343

Site index V.

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
3	41.7	36.8	4.03	37.5	340		113
						260	
4	50.9	45.1	4.61	49.4	600		150
						345	

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
5	59.4	52.8	5.12	61.2	945		190
						385	
6	66.9	59.6	5.56	72.4	1330		222
						400	
7	73.7	65.8	5.94	82.8	1730		247
						385	
8	79.6	71.2	6.26	92.1	2115		264
						360	
9	84.6	75.7	6.53	100.3	2475		275
						330	
10	88.8	79.5	6.75	107.3	2805		280
						300	
11	92.6	83.0	6.93	113.2	3105		282
						280	
12	96.0	86.1	7.09	118.6	3385		282
						255	
13	98.9	88.7	7.22	123.1	3640		280
						235	
14	101.5	91.1	7.33	126.9	3875		277
						215	
15	103.6	93.0	7.42	130.1	4090		273
						200	
16	105.7	94.9	7.49	132.6	4290		268
						185	
17	107.8	96.8	7.55	134.7	4475		263
						170	
18	110.0	98.8	7.60	136.5	4645		258
						160	
19	111.0	99.7	7.64	138.0	4805		253
						145	
20	113.0	101.5	7.68	139.5	4950		248
						135	
21	115.0	103.3	7.72	141.0	5085		242
						125	
22	116.0	104.2	7.75	142.1	5210		237
						115	
23	118.0	106.1	7.78	143.2	5325		232
						105	
24	119.0	107.0	7.80	143.9	5430		226
						100	
25	120.0	107.9	7.82	144.7	5530		221

Site index VI.

3	34.7	30.4	3.75	32.4	220		73
						180	
4	42.5	37.5	4.21	41.0	400		100
						215	
5	49.5	43.8	4.62	49.5	615		123
						240	

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
6	55.8	49.6	4.98	57.7	855		142
						250	
7	61.4	54.6	5.29	65.3	1105		158
						255	
8	66.3	59.1	5.57	72.8	1360		170
						250	
9	70.5	62.9	5.82	79.6	1610		179
						235	
10	74.0	66.1	6.04	85.8	1845		184
						220	
11	77.2	69.0	6.23	91.3	2065		188
						210	
12	80.0	71.5	6.40	96.3	2275		190
						190	
13	82.5	73.8	6.54	100.8	2465		190
						180	
14	84.6	75.7	6.67	104.9	2645		189
						160	
15	86.3	77.3	6.78	108.4	2805		187
						145	
16	88.1	78.9	6.88	111.5	2950		184
						130	
17	89.8	80.4	6.96	114.2	3080		181
						120	
18	91.2	81.7	7.03	116.5	3200		178
						110	
19	92.6	83.0	7.08	118.3	3310		174
						100	
20	94.0	84.3	7.13	119.8	3410		171
						95	
21	95.4	85.5	7.17	121.2	3505		167
						90	
22	96.8	86.8	7.20	122.4	3595		163
						80	
23	97.9	87.8	7.23	123.4	3675		160
						75	
24	98.9	88.7	7.26	124.3	3750		156
						70	
25	100.0	89.7	7.28	124.9	3820		153

Explanation:

h_t — top height in feet.

h_m — mean height in feet.

d_m — mean diameter in inches.

G — basal area sq. feet per acre.

V_d — volume cu. ft. per acre (to 3″).

i — current volume increment cu. ft. per acre (to 3″).

i — mean volume increment cu. ft. per acre (to 3″).

Table 10.

Volume Yield Table for Unthinned stands in Zululand.

Site index III.

Age	h_t	h_m	d_m	G	V_d	i	$\overline{i}$
3	55.6	49.4	5.40	68.2	1040		347
						610	
4	67.9	60.6	6.00	84.5	1650		412
						630	
5	79.2	70.8	6.46	98.2	2280		456
						640	
6	89.3	80.0	6.83	109.9	2920		487
						650	
7	98.2	88.1	7.13	119.9	3570		510
						640	
8	106.0	95.2	7.38	128.6	4210		527
						620	
9	113.0	101.6	7.59	136.2	4830		537
						590	
10	118.0	106.1	7.77	142.8	5420		542
						540	
11	124.0	111.5	7.93	148.9	5960		542
						500	
12	128.0	115.2	8.08	154.6	6460		538
						420	
13	132.0	118.8	8.22	160.1	6880		529
Site index IV.							
3	48.6	43.0	4.97	57.6	730		243
						490	
4	59.4	52.8	5.60	73.4	1220		305
						525	
5	69.3	61.8	6.09	87.1	1745		349
						540	
6	78.1	69.8	6.48	98.8	2285		381
						540	
7	86.0	77.0	6.82	109.5	2825		404
						530	
8	92.8	83.2	7.11	119.0	3355		419
						510	
9	98.7	88.5	7.36	127.6	3865		429
						490	
10	104.0	93.3	7.57	135.1	4355		436
						465	
11	108.0	97.0	7.75	141.6	4820		438
						435	

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
12	112.0	100.6	7.91	147.5	5255		438
						405	
13	115.0	103.3	8.05	152.8	5660		431
						370	
14	118.0	106.1	8.17	157.4	6030		424
						330	
15	121.0	108.8	8.27	161.3	6360		424

Site index V.

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
3	41.7	36.8	4.37	44.3	440		147
						380	
4	50.9	45.1	5.07	60.0	820		205
						400	
5	59.4	52.8	5.61	73.7	1220		244
						410	
6	66.9	59.6	6.04	85.7	1630		272
						420	
7	73.7	65.8	6.41	96.6	2050		293
						425	
8	79.6	71.2	6.73	106.7	2475		309
						420	
9	84.6	75.7	7.01	115.9	2895		322
						405	
10	88.8	79.5	7.25	124.1	3300		330
						400	
11	92.6	83.0	7.46	131.5	3700		336
						385	
12	96.0	86.1	7.65	138.4	4085		340
						370	
13	98.9	88.7	7.82	144.7	4455		343
						350	
14	101.5	91.1	7.98	150.7	4805		343
						330	
15	103.6	93.0	8.12	156.2	5135		342
						310	
16	105.7	94.9	8.24	160.9	5445		340
						290	
17	107.8	96.8	8.35	165.2	5735		337
						260	
18	110.0	98.8	8.45	169.3	5995		333

Site index VI.

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
3	34.7	30.4	3.60	29.8	180		60
						280	
4	42.5	37.5	4.33	43.5	460		115
						284	

Age	h_t	h_m	d_m	G	V_d	i	$\bar{i}$
5	49.5	43.8	4.90	55.9	744		149
						287	
6	55.8	49.6	5.38	67.6	1031		172
						288	
7	61.4	54.6	5.77	78.0	1319		188
						289	
8	66.3	59.1	6.09	84.4	1608		201
						289	
9	70.5	62.9	6.35	94.8	1897		211
						288	
10	74.0	66.1	6.60	102.5	2185		218
						284	
11	77.2	69.0	6.83	109.9	2469		224
						281	
12	80.0	71.5	7.02	116.2	2750		229
						278	
13	82.5	73.8	7.21	122.7	3028		233
						274	
14	84.6	75.7	7.40	129.4	3302		236
						269	
15	86.3	77.3	7.58	135.8	3571		238
						263	
16	88.1	78.9	7.74	141.7	3834		240
						256	
17	89.8	80.4	7.90	147.7	4090		240

Explanation: See Table 9.

The yield tables show that *E. saligna* grows quickly in early youth. Average height and diameter increment have already culminated at the age of 3 years and the culmination of current and mean annual volume increment is as follows:

Site index	Current Annual Increment		Mean Annual Increment	
	Transvaal	Zululand	Transvaal	Zululand
II	5—6 yrs.	—	—	—
III	6 yrs.	6—7 yrs.	10 yrs.	10—11 yrs.
IV	5—6 yrs.	6 yrs.	11 yrs.	11—12 yrs.
V	6—7 yrs.	7—8 yrs.	11—12 yrs.	13—14 yrs.
VI	7—8 yrs.	8 yrs.	12—13 yrs.	16—17 yrs.

The mean annual increment in the Transvaal and Zululand at the age of culmination is:

Site index	III	IV	V	VI
m.a.i. in Zululand cu. ft./acre/annum	542	438	343	240
m.a.i. in Transvaal ,,	515	392	282	190

The table shows that the difference in mean annual increment between the Transvaal and Zululand increases with decreasing site index.

2. *Volume Yield of Thinned Stands.*

Thinning experiments started in Germany towards the end of the 19th century. Wiedemann (1931, 1936) showed that a heavy thinning can increase current volume increment for some years after thinning. Eventually however, the current annual increment returns to the original level so that there were no significant differences between the total production of stands thinned to various intensities. The results of the investigations by Wiedemann have been supported by Burger (1951), Becking (1950), Møller (1954) and others and this has had an influence on the development of thinning experiments. Attention was diverted from the influence of thinning on total volume yield and was concentrated more and more on the influence of thinning on mean diameter and quality of the trees in the remaining stand. Recent publications by Assman (1954) and Mitscherlich (1954) indicate that the results of earlier investigations are open to question. Applying other methods these authors conclude that volume increment is a function of the basal area per acre. When other factors are constant basal area is dependent on stand density. The conclusions of these authors cannot be regarded as definite, but there are indications that earlier theories concerning the relation between stand density and volume production should be revised.

An attempt has been made to approach the problem by investigating the development of the heavily thinned stands on Westfalia Estate. Initially, and on the assumption that total production is not influenced by the degree of thinning the relation between the ratio $\frac{\text{number of removed trees}}{\text{number of trees before thinning}}$ and the difference between mean diameter before thinning and mean diameter of the removed trees was examined. The basic data were obtained from permanent sample plot records of the Department of Forestry and the object was to trace the development of diameter of the remaining stand for a given thinning regime. This diameter growth was compared with that of stands which had been thinned according to a designed thinning regime. A discrepancy between the theoretical development and the plot figures indicated that the assumed hypothesis should be rejected. The volume yield of the heavily thinned stands on Westfalia Estate is probably 15% lower than the volume yield of unthinned stands. It is impossible in the present investigation to test this hypothesis on a scientific basis and it must be regarded merely as a working hypothesis which needs to be verified by long-term investigations.

A yield table for heavy thinning, in Site classes III and IV and based on the assumption that total increment is 15% lower than in unthinned stands, is given in table 11.

Table 11

Yield Table for Heavily Thinned Stands in the Transvaal

Site Index III

Age	Remaining Stand							Thinning				Total Stand						Sum of thinnings cu.ft./acre	Total production cu.ft./acre	Total vol. of thinnings as % of total production
	h_{dom} (ft.)	N	G Sq.ft/acre	d_v (in.)	h_v (ft.)	V_d cu.ft/acre - 3″	S%	N	d_v (in.)	h_v (ft.)	V_d cu.ft/acre	N	G Sq.ft./acre	d_v (in.)	h_v (ft.)	V_d cu.ft./acre - 3″	S%			
$3\frac{1}{2}$	61·8	258	42·6	5·6	56·5	756	21·0	197	4·0	45	174	455	57·2	4·9	55	930	15·9	174	930	18·7
5	79·2	144	39·6	7·2	76·5	1032	22·0	114	5·5	69	396	258	57·6	6·5	74·5	1428	16·4	570	1602	35·6
8	106·0	74	46·3	10·75	99·0	1643	22·9	70	9·5	94	1149	144	81·7	10·2	97	2792	16·4	1719	3362	54·0
12	128·0	46	56·5	15·0	121·0	2385	24·2	28	13·0	117	1056	74	82·5	14·3	119	3441	19·0	2775	5160	53·8

Site Index IV

4	59·4	278	37·9	5·1	54·5	636	21·0	177	3·8	44	134	455	57·2	4·9	53	870	16·5	134	870	15·4
6	78·1	147	41·6	7·3	73·0	1045	22·0	131	5·8	65	470	278	64·1	6·6	71	1515	16·0	604	1649	36·6
9	98·7	84	48·6	10·3	91·0	1556	23·1	63	8·6	89	790	147	69·4	9·4	93	2346	17·4	1394	2950	47·3
13	115·0	58	52·6	12·9	108·0	2020	23·9	26	11·6	106	836	84	75·1	12·8	107	2856	19·8	2230	4250	52·5
18	128·0	44	59·2	15·7	120·0	2443	24·5	14	13·6	117	580	58	72·6	15·15	119	3023	21·5	2810	5253	53·5

The influence of this thinning regime on mean diameter of the stand is shown in table 12.

Table 12.

Mean Diameter in Unthinned and Heavily Thinned Stands.

	Site Class III			Site Class IV	
Age	Unthinned d_v inch	Thinned d_v inch	Age	Unthinned d_v inch	Thinned d_v inch
3.5	4.90	5.6	4	4.93	5.1
5	5.95	7.5	6	6.04	7.5
8	7.15	11.0	9	7.01	10.6
12	7.92	15.5	13	7.61	13.7
			18	7.92	16.2

The mean diameter in thinned stands, of site class III, age 12 years, and site class IV, age 18 years, is approximately double that of unthinned stands. This is due to increased growth of individual trees in stands of low density and partly to an arithmetic shift of the mean diameter.

The yield of sawtimber in heavily thinned stands.

From the volume distribution by diameter classes in unthinned and thinned stands in tables 19 and 20 the yield of sawtimber in unthinned and heavily thinned stands was calculated. The merchantable volume to a minimum top diameter of 3 inches, was converted to sawtimber volume with a minimum top diameter of 5.5 inches. The volume calculations were made for site class III, rotation 12 years, and site class IV, rotation 18 years.

Site class III, rotation 12 years.

The yield of sawtimber in unthinned stands is 4,159 cu. ft./acre, i.e. 68.5% of the yield with minimum top diameter of 3 inches. In stands thinned according to the proposed thinning regime, the yield of sawtimber in the final stand is 2,291 cu. ft., i.e. 96.1% of the yield up to a top diameter of 3 inches. The output of sawtimber from thinnings is 1,974 cu. ft., i.e. 89.5% of the yield up to 3 inch. The total volume yield of sawtimber is 4,265 cu. ft., i.e. 2.5% more than in unthinned stands.

Site class IV, rotation 18 years.

The yield of sawtimber in unthinned stands is 4,241 cu. ft., the yield of sawtimber in thinned stands, final crop and thinnings, is 2,353 and 1,928 cu. ft. respectively. The total output of sawtimber is 0.9% more than in unthinned stands.

The total yield of sawtimber is not influenced by the thinnings and the effect of increased distance between the trees on the volume of sawtimber of individual trees is offset by the influence of a heavy thinning on the volume increment per acre. But the recovery of sawn

timber increases with increasing diameter. The S.A. General Investment and Trust Co. supplied data of the recovery from logs of different diameters. The length of the logs was 12—16 ft. This recovery, in terms of the volume of sawn boards after seasoning, expressed as a percentage of the log volume is given in table 13.

Table 13.

Relation between Top Diameter of Log and Recovery of Sawn Timber.

Top diameter inches	Output of sawn timber in % of round wood volume
4	26.5
6	33.0
8	38.0
10	41.0
12	44.0
14	47.0
16	49.0
18	51.0

Scott (1950) found, after many experiments in State sawmills, a mean saw recovery of 41%, but he did not detail the relation between diameter and recovery. By combining the yield table data and the taper data of table 1 the yield of sawn boards recoverable from trees of each diameter class can be determined. These determinations for trees of 8—16 inches d.b.h. are given in table 14.

Table 14.

Output of Sawn Timber of Trees.

d.b.h. inches	Volume of sawn timber as % of roundwood volume
8	33.1
9	34.7
10	35.9
11	37.1
12	38.1
13	39.1
14	40.1
15	41.0
16	41.9

The roundwood yield of thinned stands as given by the yield table for heavy thinning can be converted to the volume of sawn timber. In site class III, rotation 12 years, the total volume yield of sawn timber in unthinned and thinned stands is 1,372 and 1,674 cu. ft. respectively, in site class IV, rotation 18 years, it is 1,400 and 1,695 cu. ft. respectively. In both site classes the yield of sawn timber in heavily thinned stands is 21—22% higher than in unthinned stands.

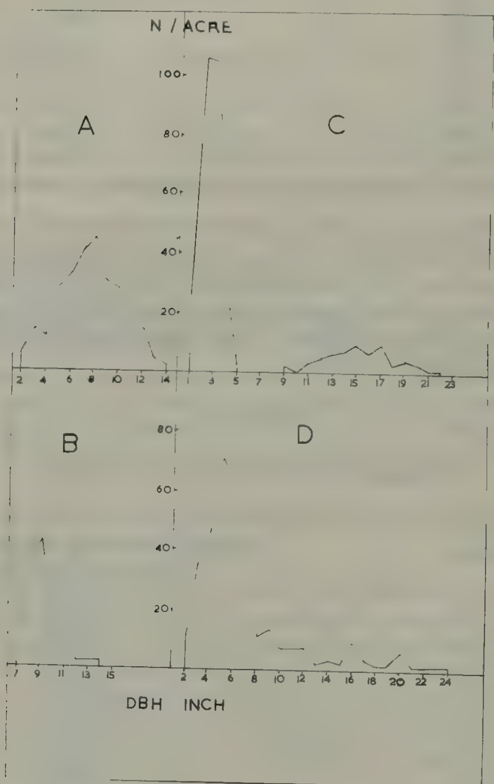
3. *Frequency Distribution of Diameter Classes in E. saligna stands.*

The mean diameter of a stand is not sufficient to characterise the diameter distribution of that stand, because stands with a different frequency distribution over diameter classes can have the same mean diameter and vice versa. When the frequency distribution is normal or approximately normal, the distribution can be characterised completely by mean and standard deviation.

The following types of frequency distribution occur in saligna stands:

1. Symmetrical distribution. This type occurs in even-aged stands, where thinnings have not been carried out, also in many cases of thinned even-aged stands (fig. 11A).

Figure 11.



Some types of frequency distribution of d.b.h. classes.

2. Skew distribution. The commonly used method of thinning begins with the removal of suppressed trees and works upwards. The effect of this low thinning is to change the normal distribution to a positively skewed distribution, because thinning is concentrated on suppressed and dominated trees. This type of distribution is found in even-aged thinned stands (fig. 11B).

3. A double-peaked distribution is found in uneven-aged stands, consisting of two age classes, namely coppice under standards. The

single components may show a normal or skew distribution (fig. 11C).

4. In some cases, the stand is a mixture of three age classes, the frequency distribution of each age class cannot usually be recognised (fig. 11D).

The types 3 and 4 are seldom found and do not merit further consideration, but the occurrence of types 1 and 2 requires examination.

The test of normality was restricted to the test of symmetry as stated by the ratio $g_1 = \dfrac{k_3}{k_2 \sqrt{k_2}}$ in which the constants k_2 and k_3 are determined by the second and third moments of the distribution with respect to the mean. The symmetry of the distribution was tested in 25 thinned and 11 unthinned stands, with the following result:

1. Departure from symmetry in the group of thinned stands was significant at a level of 1% in 12% of the samples and at a level of 5% in 16% of the stands. In the other stands no significant asymmetry was found.

2. Within the group of unthinned stands no significant departure from normality was found.

While there is thus a slight tendency towards positive skewness in thinned stands, the degree of skewness is not serious and no useful purpose is served by transformation to a normal distribution.

The relation between mean diameter and standard deviation in thinned and unthinned stands was examined. There are indications that the regression is curvilinear and a second degree polynomial has therefore been fitted. The result is given in table 15.

Table 15.

Relation between Arithmetic Mean Diameter ($\bar{d}$) and Standard Deviation (S_d) in Thinned and Unthinned Stands

$\bar{d}$ (inches)	Standard deviation S_d (inches) Unthinned Stands	Thinned Stands
4	1.14	—
5	1.54	0.83
6	1.88	1.00
7	2.15	1.16
8	2.36	1.32
9	2.52	1.48
10	—	1.63
11	—	1.77
12	—	1.91
13	—	2.04
14	—	2.16
15	—	2.28
16	—	2.40
17	—	2.51
18	—	2.61
19	—	2.71
20	—	2.80

To compute the regression of the diameter of the tree with the mean volume (d_v) on $\bar{d}$, the following method was adopted. The relation between volume and d.b.h. is given by Berkhout's formula:

$V = a\, d^b$, where

V = total volume of the tree

d = d.b.h.

a and b = constants of the equation.

The value of b for *E. saligna* was found to be 2.576.

Essed (1958) has derived a formula, giving the relation between $\bar{d}$ and d_v

$$d_v = \bar{d}\,(1 + \tfrac{1}{2}\,(b-1)\,S_d^2\,\bar{d}^{-2})$$

where

$\bar{d}$ = arithmetic mean diameter

b = regression coefficient from Berkhout's formula

S_d = standard deviation

d_v = diameter of the tree with the mean volume.

Table 15 gives the standard deviation S_d by diameter classes for unthinned and thinned stands. Values of d_v by Essed's formula were calculated for thinned and unthinned stands and the result is given in table 16.

Table 16.

Relation between $\bar{d}$ and d_v in Unthinned and Thinned Stands.

Unthinned stands		Thinned stands	
$\bar{d}$ (inch)	d_v (inch)	$\bar{d}$ (inch)	d_v (inch)
3.5	3.68	5	5.11
4.0	4.25	7	7.15
4.5	4.81	9	9.19
5.0	5.37	11	11.22
5.5	5.90	13	13.25
6.0	6.45	15	15.27
6.5	7.00	17	17.29
7.0	7.51	19	19.30
7.5	8.04	21	21.31
8.0	8.56	23	23.32
8.5	9.04	25	25.32

The yield tables give the mean diameter d_v for each site index and age. The corresponding arithmetic mean diameter can be read from

table 16 and the standard deviation from table 15. The frequency distribution over diameter classes can be computed with a table for cumulative frequencies of a normal distribution. The calculations have been completed for the yield tables of unthinned and thinned stands in the Transvaal. The result is given in tables 17 and 18.

Table 17.

Number of Stems per Acre in Unthinned Stands in the Transvaal.

Site index II.

dbh Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
3	5	27	78	128	120	64	20	3							445
4	4	16	43	82	106	97	61	27	8	1					445
5	3	11	28	58	85	95	82	49	24	8	2				445
6	3	8	22	44	70	87	84	65	37	17	6	2			445
7	2	7	17	35	59	79	82	72	49	26	12	4	1		445
8	2	6	15	30	53	72	82	75	54	32	16	6	2		445
9	1	5	13	27	47	67	80	75	59	38	20	9	3	1	445

Site index III.

3	5	30	89	140	115	52	12	2							445
4	3	19	52	96	115	93	47	16	4						445
5	3	13	36	70	95	152	62	10	4						445
6	3	10	27	53	83	94	82	53	26	10	3	1			445
7	2	8	22	44	71	87	86	63	37	17	6	2			445
8	2	7	18	38	62	82	83	70	45	24	10	3	1		445
9	2	6	16	33	56	76	83	73	52	29	13	5	1		445
10	2	5	14	30	52	72	82	74	55	34	16	7	2		445
11	2	5	13	27	47	69	79	75	59	37	20	8	3	1	445
12	1	4	12	25	45	65	79	76	60	41	22	10	4	1	445

Site index IV.

3	6	36	111	152	103	32	5								445
4	5	24	66	114	121	77	30	7	1						445
5	4	16	46	84	110	96	57	24	7	1					445
6	4	13	35	66	94	98	74	40	16	4	1				445
7	3	10	27	55	81	95	81	53	26	10	3	1			445
8	2	9	23	46	73	89	84	62	35	16	5	1			445
9	2	8	20	41	65	73	87	70	44	23	8	3	1		445
10	2	7	18	37	61	80	84	70	47	24	11	3	1		445
11	2	6	16	35	57	76	84	73	50	28	13	4	1		445
12	2	6	16	31	54	75	80	74	53	31	15	6	2		445
13	2	5	14	30	52	72	82	74	56	33	16	7	2		445
14	2	5	13	28	51	68	81	76	56	36	18	7	3	1	445

dbh Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
15	2	5	13	27	48	68	80	75	58	38	19	8	3	1	445
16	2	4	13	27	47	67	80	75	60	38	20	8	3	1	445
17	1	5	12	26	45	66	79	77	59	40	21	10	3	1	445
18	1	5	12	25	45	66	77	76	60	41	22	10	4	1	445

Site index V.

3	6	42	125	159	89	22	2								445
5	4	21	59	105	119	85	39	11	2						445
7	4	13	36	70	97	98	71	37	14	4	1				445
9	3	10	26	52	78	94	82	55	29	11	4	1			445
11	2	8	20	42	68	87	85	65	40	18	7	3			445
13	2	7	18	37	61	80	83	70	47	25	10	4	1		445
15	2	6	16	33	56	76	82	73	52	29	14	5	1		445
17	2	6	14	32	53	72	83	73	54	32	16	6	2		445
19	2	5	14	30	51	71	81	75	55	34	17	7	2	1	445
21	2	5	13	29	49	70	78	76	57	36	18	8	3	1	445
23	2	5	13	28	48	68	78	75	60	37	19	8	3	1	445
25	1	5	13	27	47	67	79	75	61	37	20	9	3	1	445

Site index VI.

3	6	53	154	163	61	8									445
5	6	28	81	132	119	60	17	2							445
7	4	19	53	97	116	90	46	16	4						445
9	3	15	38	73	102	100	67	32	12	3					445
11	3	11	31	60	88	97	77	48	21	7	2				445
13	3	10	25	52	80	91	83	57	28	11	3	2			445
15	2	9	23	45	72	90	84	62	35	16	5	2			445
17	2	8	21	41	68	84	85	66	40	20	8	2			445
19	2	7	19	39	64	83	85	68	44	21	9	3	1		445
21	2	7	18	37	63	80	84	70	45	24	10	4	1		445
23	2	7	18	36	61	79	85	70	47	25	10	4	1		445
25	2	7	17	36	58	79	85	71	47	26	12	4	1		445

Table 18.

Number of Stems per Acre in Thinned Stands in the Transvaal.

Site index III.

dbh Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
3½			4	33	94	93	30	4														258
5				2	11	33	47	35	13	3												144
8						1	2	6	12	16	16	12	6	2	1							74
12										1	2	4	6	8	8	7	5	3	1	1		46

Site index IV.

Age / dbh	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
4	10	67	127	65	9															278
6		2	11	31	48	37	15	3												147
9				1	4	9	16	21	17	10	4	2								84
13						1	2	5	8	11	11	9	6	3	2					58
18								1	1	3	4	6	7	8	6	4	2	1	1	44

4. *Volume Distribution over Diameter Classes.*

Tables 17 and 18 give the frequency distribution in 1 inch diameter classes in unthinned and thinned stands in the Transvaal. In order to transform these to tables, giving the volume distribution over diameter classes, the mean volume and consequently the mean height of each diameter class must be known.

For each sample plot, the height curve $h = a_0 + a_1 \log d.b.h.$ was calculated and the regression coefficient a_1 was correlated with the factors log age, site index and S%. The analysis of multiple regression shows, that the contribution of age and site index to the regression is highly significant. The regression equation is:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3$$

where:

X_1 = log age
X_2 = site index
X_3 = S%
b_0 b_1 b_2 b_3 = constants of the equation.

The results were as follows:

$b_0 = 17.8209$
$b_1 = 20.3834$ $\quad Sb_1 = 1.837$ $\quad t = 11.10$ $\quad t^* = 1.97$ $\quad t^{**} = 2.60$
$b_2 = -2.7473$ $\quad Sb_2 = 0.371$ $\quad t = 7.41$ $\quad t^* = 1.97$ $\quad t^{**} = 2.60$
$b_3 = -0.1393$ $\quad Sb_3 = 0.096$ $\quad t = 1.45$ $\quad t^* = 1.97$ $\quad t^{**} = 2.60$

The slope of the height curve is steeper, when the site index is higher and the stands are older. The result of the computation of volume distribution over diameter classes is given in tables 19 and 20.

Table 19.

Volume Distribution over D.B.H. Classes in Unthinned Stands in the Transvaal. ...

(cu. ft. per acre)

Site index II.

dbh / Age	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
3	143	289	252	113	23														820
6	72	254	504	712	750	564	329	140	55										3380
9	58	212	491	861	1095	1136	921	588	316	124	48								5850

Site index III.

Age \ dbh	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
3	139	242	175	60	14														630
6	78	269	487	616	530	348	170	62	25										2585
9	60	224	494	791	953	892	627	345	157	37									4580
12	53	202	479	861	1111	1161	993	649	349	164	48								6070

Site index IV.

3	141	195	100	24										460
6	85	268	450	499	368	191	61	18						1940
9	63	223	401	693	758	634	413	175	79	31				3470
12	57	216	486	751	953	900	658	391	185	73				4670
15	55	206	479	835	1064	1086	882	539	270	118	46			5580
18	52	205	491	850	1152	1181	1014	660	358	168	49			6180

Site index V.

3	124	150	58	8										340
7	85	258	418	437	307	152	56	17						1730
11	62	220	454	638	662	541	307	146	75					3105
15	55	204	446	696	846	789	554	326	141	33				4090
19	54	201	449	747	952	917	722	438	215	70	40			4805
23	55	200	460	755	1012	1067	827	527	263	115	44			5325

Site index VI.

3	112	90	18											220
7	105	269	337	241	116	37								1105
11	76	249	432	507	419	244	102	36						2065
15	63	221	450	606	600	454	264	100	47					2805
19	58	209	440	647	696	599	363	191	77	30				3310
23	56	210	440	681	774	694	458	224	107	31				3675

Table 20.

Volume Distribution over d.b.h. Classes in Thinned Stands in the Transvaal.
(cu. ft. per acre)

Site index III.

Age \ dbh	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
3½	33	210	330	155	28														756
5	3	34	153	318	319	158	47												1032
8			6	16	70	187	312	387	341	202	77	45							1643
12							22	55	132	230	363	419	414	340	230	86	94		2385

Site index IV.

Age \ dbh	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
4	69	286	234	47															636
6	3	31	141	319	328	177	46												1045
9			5	31	95	223	374	372	264	122	70								1556
13					12	33	104	203	330	391	371	288	165	123					2020
18							22	27	97	150	265	357	462	400	302	169	92	100	2443

CHAPTER VII

WORKING TECHNIQUE OF FELLING AND SUBSEQUENT PRIMARY CONVERSION

Costs of felling and subsequent operations, expressed in cents per cu. ft. vary widely, because of a number of factors, including the productivity of individual labour, the work method, the equipment used, organisation of the work, age of stand, genetic qualities of the tree and the configuration of the terrain. Analysis of the labour process by time studies is desirable for the following purposes:

(1) Collection of reliable data as a basis for economic computations.

(2) Establishing of uniform piece rates for felling and other operations.

(3) Increasing the productivity of the labour.

Time studies were undertaken at the following plantations:

1. Plantation in the Graskop area, Eastern Transvaal. A 7-year old stand, on flat terrain, mean diameter 7.5 inches. The timber is converted to mining poles. Felling is done by gangs of 12 labourers. The gangs are subdivided into groups, each group being responsible for a given operation.
2. Plantation in the Graskop area, Eastern Transvaal. A 13-year old stand, situated on steeply undulating terrain, mean diameter 10.5 inches. The wood, to a top diameter of 5.5 inches, is converted into sawlogs. Felling, debranching, debarking and cross-cutting are completed by gangs of two labourers. Maintenance of tools could be improved and the rate of performance of the work is below normal. Time, taken for debarking is appreciable because the bark is difficult to remove. The time values therefore incorporate several unfavourable factors.
3. Plantation in the Graskop area, Eastern Transvaal. A 9-year old stand, converted into mining timber, situated on flat terrain, mean diameter 7 inches. Felling, debranching and debarking are completed by individual labourers. Rate of the work is normal.
4. Plantation in the White River area, Eastern Transvaal. A 7-years old stand, converted into mining timber and pulpwood, flat terrain, mean diameter of the trees 7 inches. Felling, debranching and debarking are carried out by teams of 12—15 labourers. The rate of the work is low.
5. A plantation in the Kwambonambi area, Zululand. Stand is 11 years old, situated on flat terrain, mean diameter 8 inches. Timber is utilised as pulpwood. Felling, debranching, debarking and cross-cutting are completed by gangs of two labourers. The rate of the work is normal.

Both working time required to complete the various operations at every tree, and lost time, the time elapsing between two successive operations were recorded. Lost time includes:

(i) walking time for transportation of labourers and tools from one place of operation to the next;

(ii) relaxation or rest time.

The following operations were analysed: felling, debranching, debarking and cross-cutting.

Felling:

Felling requires more skill than the other operations of primary conversion. If felling is not done skilfully a considerable waste of timber, due to splitting of the stem, may occur. For the bigger trees, it is advisable to notch with an axe and cross-cut with a two-mean saw. Stump heights should be kept as low as possible to avoid unnecessary timber losses.

Because the shortest felling time does not always yield the best results, it is important to develop a satisfactory working technique and then lay down piece rates based upon this.

Felling time is dependent on felling technique, on diameter of the tree, on the rate of the labourer, and on the equipment. Felling is usually done with a two-man saw, but in the Driekop plantation trees are felled by axe. This latter method has the following disadvantages:

(1) Felling time per tree is higher.

(2) An additional cut at the base of the stem is necessary in order to cut it level.

(3) Waste of timber is higher, approximately 4% of the total volume.

Felling by axe has the advantage that the work is completed by individual labourers so that lost time is usually less. Moreover, waste of timber, through stem splitting is small.

Lost time recorded in the groups 1—5 was:

Group 1	28.2	sec. per tree
Group 2a	87.6	,, ,, ,,
Group 2b	91.6	,, ,, ,,
Group 3	8.9	,, ,, ,,
Group 4a	90.6	,, ,, ,,
Group 4b	63.6	,, ,, ,,
Group 5	78.3	,, ,, ,,

A general average of the measured lost time values is not suitable for setting piece rates. In group 2a for example, the lost time is 39% of total working time. It is preferable to allot a general rest allowance expressed as a percentage of the total working time. This time value has to cover relaxation time, time for preparatory operations before the work starts, and time for maintenance of tools. Walking time between two successive operations has been fixed at 10 sec. per man per tree, independent of the diameter of the tree.

The actual felling time has been correlated with breast height diameter of the tree and fitted by a second degree equation. The result is given in table 21.

Table 21.

Relation between D.B.H. and Felling Time per Tree.

d.b.h. o.b. (inches)	Felling time (sec./tree) (2-man crews)	Total lost time sec./tree	Total time sec./tree
3	7	20	34
4	13	20	46
5	21	20	62
6	31	20	82
7	43	20	106
8	56	20	132
9	72	20	164
10	90	20	200
11	110	20	240
12	132	20	284
13	156	20	332

Debranching:

The technique of debranching requires less training than felling. Branches are cut from the lower side, i.e. from the base toward the top of the tree. Danger of accidents can be minimised by correct positioning of the axeman, who should stand on the side of the log opposite to the branches he is cutting. Differences between times of debranching in different groups are due to the rate of performance of the labourer, the quality of the work done and diameter and density of the branches.

Debranching is often done carelessly leaving protruding branch stubs; these must be removed but this is generally done during cross-cutting operations. Branch diameter is related to age and distance between the trees. It increases with both increasing age and increasing distance between the trees. Time values for debranching were plotted against breast height diameter of the trees and fitted by a second degree polynomial. Since the rate of the workers in group 4 was far below normal, this group of observations had to be excluded. The measured lost-times in groups 1—5 were as follows:

Group 1: 13.8 sec./tree.
Group 2: 40.3 ,, ,,
Group 3: 8.9 ,, ,,
Group 4: 35.9 ,, ,,
Group 5: 0 ,, ,, (debranching is followed immediately by debarking)

The lost times are relatively low, because:

(1) Debranching is done by individual labourers.

(2) Debranching does not require as much energy as felling.

The allowable walking time is again fixed at 10 sec. per tree. The time for debranching has been correlated with the breast height diameter of the tree, but since the quality of the work is not satisfactory, it is

desirable to pay more attention to careful debranching. The construction of the table is based on the assumption that the actual time values will be 100% higher than the measured time-values if the work is performed carefully. The results are given in table 22.

Table 22.

Relation between D.B.H. and Time for Debranching per Tree.

d.b.h. o.b. (inches)	Mean time of debranching sec./tree	Lost time sec./tree	Total time sec./tree
3	24	10	34
4	44	10	54
5	68	10	78
6	96	10	106
7	126	10	136
8	162	10	172
9	200	10	210
10	242	10	252
11	288	10	298
12	338	10	348
13	390	10	400
14	448	10	458

Debarking:

Debarking is usually done in two phases, partly on the standing tree and partly on the felled tree. This working method is preferable when the bark can be removed easily.

The amount of energy which has to be employed in order to remove the bark is dependent upon two factors:

(1) Genetic. The hybrid planted in Eastern Transvaal develops a thick bark, difficult to remove. Measurements at Waterhoutboom showed that the mean bark thickness of trees with a breast height diameter of 10 inches was 1.0 inch; this is 0.43 inches more than the mean bark thickness of saligna.

(2) Growth activity of the trees. In Zululand plantations a number of suppressed trees dies off as the stands get older. This is preceded by a decrease in the flow of sap so that the bark is not easy to remove.

Debarking is usually performed by axe but sometimes with a spoon-shaped wooden instrument. It is possible that better results can be obtained by employing specially designed debarkers, but preliminary experiments did not give encouraging results. Labourers become familiar with certain tools and do not readily change to new ones. The problem has also physiological aspects, as it is possible that energy could be used profitably if specially designed debarkers were employed.
The lost times which were found, are:

Group 1: 42.3 sec. per tree
Group 2: 55.2 ,, ,, ,,
Group 3: 8.9 ,, ,, ,,
Group 3: 62.0 ,, ,, ,,
Group 5: 22.5 ,, ,, ,,

Walking time was again fixed at 10 sec. per tree. Debarking time was plotted against diameter at breast height. In contrast with both felling and debranching, a linear relation exists between d.b.h. and debarking time. The result is given in table 23.

Table 23.

Relation between D.B.H. and Debarking Time in Stands with Normal Bark Thickness.

d.b.h. (inches)	Debarking time sec./tree	Lost time sec./tree	Total sec./tree
3	290	10	300
4	320	10	330
5	350	10	360
6	380	10	390
7	410	10	420
8	440	10	450
9	470	10	480
10	500	10	510
11	530	10	540
12	560	10	570
13	590	10	600
14	620	10	630

Cross-cutting:

Cross-cutting is usually done with the bow saw by two-man teams. The productivity of cross-cutting with the Homelite power saw was investigated at the plantations of the S.A. Pulp and Paper Co. When powersaws are employed, the work is usually completed by three-man teams. The first labourer handles the powersaw, the second puts down the stem in such a manner that sawing is not interrupted and the third labourer is employed with marking the log length.

Log length for mining-timber and pulpwood is mostly 8 feet and for sawlogs between 10 and 20 ft. Conversion into telephone and transmission poles is of secondary importance and can be ignored. Cutting of mining poles is left until 5—6 weeks after felling, to ensure appropriate reduction of moisture content. Sawing time per log is dependent on diameter, rate of the labourer and maintenance of the bowsaw. The sawing time per tree is also dependent on the number of logs per tree and therefore on the height/d.b.h. ratio of the tree. This ratio is determined by age, S% and site class. The measured lost times are:

Group 1 : 15.1 sec. per log per team.
Group 2a: 35.9 ,, ,, ,, ,, ,,
Groub 2b: 33.0 ,, ,, ,, ,, ,,
Group 3 : 33.0 ,, ,, ,, ,, ,,
Group 4 : 31.3 ,, ,, ,, ,, ,,
Group 5 : 23.2 ,, ,, ,, ,, ,,

An average allowable walking time of 10 sec. per log per team can be accepted, but an additional preparation time has to be considered, which can also be fixed at 10 sec. per log per team. The total lost time

per log is therefore 40 sec. The sawing time has to be correlated with diameter at place of sawing. A second degree equation was fitted to the observations and the result of the computations is given in table 24.

Table 24.

Relation between Log Diameter and Time of Cross-cutting.

Diameter at place of cutting (inches)	Sawing time sec./log (2-man crews)	Total lost time sec./log	Total time sec./log
2	2.0	40	44
3	4.0	40	48
4	7.4	40	55
5	11.4	40	63
6	18.0	40	76
7	27.0	40	94
8	38.6	40	117
9	52.6	40	145
10	69.2	40	178
11	88.3	40	217
12	109.9	40	260
13	134.0	40	308

Breast height diameter, the diameter at the places of cutting and the corresponding sawing times of 120 trees in Zululand have also been measured. The log length was mostly 8 feet. Since it was desirable to eliminate the productivity of the work of one special team, the measured times at each place of cutting were replaced by the mean times, derived from the regression equation. From this the total sawing time, excluding lost time per tree, was computed, and was correlated with d.b.h. of the trees and the lost time, derived from the expected number of logs per tree, was added. The result is given in table 25.

Table 25.

Total time of cross-cutting per tree, into 8 ft. logs incl. lost time.

d.b.h. (inches)	Total working time incl. lost time sec./tree
3	105
4	233
5	332
6	415
7	500
8	589
9	680
10	783
11	893
12	1009
13	1137
14	1276

Cross-cutting with powersaws:

Power saws are used increasingly, particularly in those districts of the Northern and Eastern Transvaal where labour is scarce. A time study of cross-cutting with the Homelite power saw was carried out in the plantations of the S.A. Pulp and Paper Co. in Eastern Transvaal, and gave the following results:

The mean lost time per log of 6.6 seconds is lower than the measured time for the bowsaw.

This is due to the following factors:

(1) With bowsaw cross-cutting marking is combined with sawing. When power saws are used it is done separately.

(2) When the bowsaw is used the mean walking distance per log is greater because each tree is cut completely, before the labourer starts with the next one. With the power saw, the labourers cut several trees simultaneously.

(3) Cross-cutting with bowsaw requires more space because the bowsaw moves in a horizontal direction.

The allowable walking time was fixed at 7 sec. per log. The sawing time of each log was correlated with the corresponding diameter. The relation is curvilinear and a second degree polynomial was fitted to the observations. The table is based on the assumption that the work is completed by teams of three labourers. The result is given in table 26.

Table 26

Comparison between Cross-cutting into 8 ft. Logs with Power Saw and Bowsaw

Diameter u.b. inch	Powersaw				Bowsaw	Working Time Powersaw in % of Bowsaw
	Sawing Time Sec/log	Lost Time Sec/log	Total Time Sec/log Team	Total Time Sec/log	Total Time Sec/log	
2	3·5	7	10·5	31	44	72
3	4·0	7	11·0	33	48	69
4	4·5	7	11·5	34·5	55	63
5	6·7	7	13·7	41	63	65
6	10·9	7	18·6	56	76	74
7	16·9	7	23·9	72	94	77
8	24·8	7	31·8	95	117	81

The table shows that time saved is greatest in the 4 inch diameter class. When the stems are converted into mining props and pulpwood, the time saved is 30—35%. The result might be different if it were possible to complete the work in teams of two labourers. The total time of cross-cutting a tree with a diameter of 5 inches would then decrease to 27 sec. (incl. lost time). This corresponds to 43% of the time required for cross-cutting with the bowsaw.

These computations are based on the assumption that the powersaw works continually and that there are not mechanical stoppages. This assumption is not valid as stoppages occur frequently, especially when the powersaws are handled by unskilled labourers. These stoppages lead to high waste times. The actual saving of time therefore will not be more than 50% of the theoretical time saving. The total time required

for making a 5-inch cross-cut is 41 sec. if a power saw is employed and cross-cutting is done by three-man teams. This corresponds to 0.11c per log, if wages are assumed to be 0.159c per minute. When the work is completed by bowsaw by two-man teams, the costs are 0.166c per log. When cross-cutting with the powersaw can be completed by two-man teams, the costs per log will be 0.075c. According to the Department of Forestry, the operating costs of a well-known power saw are:

Depreciation	R0.275	per hour
Repair and fuel ...	R0.275	,, ,,
Interest	R0.017	,, ,,
Total	R0.567	,, ,,

The operating costs for the power saw to prepare a pole with a top diameter of 5 inches are 0.216c which has to be compared with a maximum saving of wages of 0.09c. The costs of depreciation of the bowsaw are not included in these computations, but they are so low that they can be ignored.

The power saw is economical in America, where the ratio of the price of the power saw to the weekly wages of the labourer is 2 : 1. This ratio, at the present level of wages of labourers in South Africa is approximately 108 : 1, so that it is not attractive, from a financial point of view, to introduce power saws. This is generally recognised, but the justification of their use in South Africa has been to relieve the labour shortage.

The question arises, however, of whether the solution of labour problems should be sought in the mechanisation of felling and cross-cutting. Time studies in Europe have shown that the productivity of felling and other operations can be raised considerably by improvement in working methods. As a result of these investigations there is an increasing tendency to complete felling and cross-cutting in one-man teams. Such working methods can also be recommended in saligna plantations, especially in plantations supplying small dimension mining timber and pulpwood. Other means of raising the productivity of the work can be sought in better equipment and improved maintenance of this equipment. In the present phase of development of forest labour more attention should be paid to improving existing manual working methods rather than mechanisation of the work.

Additional Operations:

When cross-cutting is completed, the poles or logs are stacked and then transported to station or sawmill. It is sometimes necessary in irregular terrain to skid the timber from the plantation to the road. The average time taken to stack mining timber in the plantations of the S.A. Pulp and Paper Co. is 21 sec. per pole, in the plantations of the S.A. General Investment & Trust Co., 12 sec., and in Roodewal plantation 27 sec. The average time for stacking mining timber and pulpwood on piles within the stand on flat terrain, can be fixed at 20 sec. per pole.

The next operation is to pile the slash, that is, the branches and unsaleable portion of the crown, in rows in the stand. The time per tree is dependent on the number of branches, which is related to the stem diameter, and on the distance to the rows. The relation between the stem diameter and time is given in table 27.

Table 27.

Time for Carrying of Slash to Rows Approximately 40 feet Apart.

d.b.h. inches	Time sec./tree
3	6
4	9
5	14
6	21
7	32
8	46
9	62
10	78
11	95
12	112
13	130
14	150

When possible, the timber is loaded on lorries in the stand and not along the road. In that case improvised plantation roads have to be contructed. The cost of these has been estimated at R0.75 per acre.

Summary:

In the preceding sections the relation between diameter and working time of different operations has been analysed. These mean times are summarised in table 28.

Table 28

Summary of Mean Times of Felling and Subsequent Primary Conversion

d.b.h. inches	Time in sec/tree							Time in % of total time					
	Felling	Debranching	Debarking	Cross-cutting	Stacking	Slash piling	Total	Felling	Debranching	Debarking	Cross-cutting	Stacking	Slash piling
3	34	34	300	105	44	6	523	6·5	6·5	57·4	20·1	8·4	1·1
4	46	54	330	233	98	9	770	6·0	7·0	42·9	30·2	12·7	1·2
5	62	78	360	332	130	14	976	6·3	8·0	37·0	34·0	13·3	1·4
6	82	106	390	415	150	21	1164	7·0	9·1	33·6	35·6	12·9	1·8
7	106	136	420	500	166	32	1360	7·8	10·0	30·8	36·8	12·2	2·4
8	133	172	450	589	178	46	1568	8·5	10·9	28·7	37·6	11·4	2·9
9	165	210	480	680	186	62	1783	9·3	11·8	26·9	38·1	10·4	3·5
10	201	252	510	783	194	78	2018	10·0	12·5	25·3	38·7	9·6	3·9
11	241	291	540	893	200	95	2267	10·6	13·1	23·9	39·4	8·8	4·2
12	285	348	570	1009	204	112	2528	11·3	13·8	22·5	39·9	8·1	4·4
13	332	400	600	1137	208	130	2807	11·8	14·3	21·4	40·5	7·4	4·6
14	384	458	630	1276	212	150	3110	12·3	14·8	20·3	41·0	6·8	4·8

It can be seen that debarking time, as a percentage of the total time, increases with increasing diameter, whilst the relative time of the other operations in general decreases.

Piece rate and labour costs:

The task system, as applied in forest plantations in South Africa is a piece rate system, but instead of giving a reward for each job performance, a daily task is laid down which must be performed to obtain a given reward per day. It means that good and bad labourers obtain the same monetary reward per day, but the working-hours of the good labourer are shorter than those of the inefficient labourer.

Whilst it is not recommended for labourers in Europe, it is adapted to the mentality of labourers in South Africa. Since the task system is essentially a piece rate one, it must be possible, with average performance, to accomplish the task in 75% of the complete working-day. If the latter is fixed at 540 minutes, the effective working time is 405 minutes. Felling and related operations make heavy physical demands on the labourer and a general rest allowance has therefore to be provided. According to European time studies, this general rest allowance is fixed at 30%. It comprises not only an allowance for relaxation, but also the time needed for maintenance of tools and preparation for work. This further reduces the actual working-time to 312 minutes.

Before drawing up piece rates, it is important to ensure that the job is being efficiently done and the correct tools employed. Application of this principle of rationalising the labour, to forest operations in South Africa does not give results which are immediately satisfactory. Improvement of existing working methods and equipment with an increase in productivity will take time. The day-task cannot therefore be based on ideal methods and equipment.

Before determining the day-task, the organisation of the labour force must be considered. Is it advisable to organise the labour force into specialised gangs, each gang being responsible for one operation either felling, debranching, debarking or cross-cutting? This method has several disadvantages:

(1) The lost time is high. The average lost time in the plantations of S.A. Pulp and Paper Co., where felling and conversion are organised in gangs, is 175 sec. per tree. In Driekop, where all operations are completed by one-man teams, the average lost time per tree is 27 sec.

(2) The reward of the individual labourers is not dependent on the individual performance, but is determined by the performance of the gang, which is fundamentally wrong.

(3) Physiological investigations, carried out in Germany, have shown that different groups of muscles are active in different operations. Excessive use of certain groups of muscles can be avoided if the work is organised in one-man teams.

Felling and conversion by gangs of specialised labourers cannot therefore be recommended. The computation of the day task is based upon the assumption that for felling and other operations the labour force is organised in two-man teams. When the timber is converted to

mining props, it is desirable to determine the daily task for cross-cutting separately from felling, debranching and debarking, since cross-cutting is done several weeks after felling. The table for the day-task of felling, debranching and debarking uses breast height diameter as its starting point. The relation between diameter and time is almost linear. When the day task in a certain stand has to be determined, the arithmetic mean diameter of the trees can be computed and the task read off from the table. The task for cross-cutting of mining poles is based on the top-diameter of the poles. The relation between diameter and time is curvilinear and it is not permissible to compute the arithmetic mean diameter of the logs in order to determine the task. The top diameter of all poles must be measured and the allowable time read off from the table, in order to compute the total allowable time for a given number of poles. If, however, it is impossible or impractical to complete these measurements, the arithmetic mean top diameter can be computed from a number of observations. The allowable time can be read off from the table, but the result has to be multiplied by a factor, which is dependent on the frequency distribution over diameter classes. This correction factor is estimated at 1.12. The data necessary to compute the daily task are summarised in table 29.

Table 29

Daily Task of Conversion to Mining Timber

Task for felling, debranching, debarking				Task for cross-cutting		
d.b.h. inches	Felling, debranching and debarking min/tree	Day-task two labourers (number of trees)	Top diameter of poles (inches)	Cross-cutting sawing time min/pole	Day-task cross-cutting two labourers (number of poles)	Corrected task if arithmetic mean top diameter is computed (number of poles)
3	6·1	—	2	0·73	854	—
4	7·2	—	3	0·80	780	709
5	8·3	—	4	0·92	678	617
6	9·6	65	5	1·05	594	540
7	11·0	57	6	1·27	492	447
8	12·6	49	7	1·57	398	—
9	14·2	44	8	1·95	320	—
10	16·1	—	9	2·42	258	—
11	18·0	—	10	2·97	210	—
12	20·0	—	11	3·62	172	—
13	22·2	—	12	4·33	144	—
14	24·5	—	13	5·13	122	—

When the timber is converted into sawlogs or pulpwood every team has to complete the whole job, namely felling, debranching, debarking, cross-cutting, stacking and carrying of slash to rows.

The computation of the daily task has to be based on a mean length of 8 feet for pulpwood poles and 16 feet for sawlogs. It is

assumed, moreover, that pulpwood will be produced from unthinned stands and sawlogs from thinned stands. The result is given in table 30.

Table 30

Daily Task for Conversion into Pulpwood or Sawlogs and Pulpwood. (Daily task includes felling, debranching, debarking, cross-cutting, stacking and carrying slash to rows)

	Conversion into Pulpwood		Conversion into Sawtimber	
d.b.h. inches	Felling and primary conversion min/tree	Day-task for two labourers (number of trees)	Felling and primary conversion min/trees	Day-task for two labourers (number of trees)
3	8·7	—	—	—
4	12·8	—	—	—
5	16·3	38	—	—
6	19·4	32	19·6	32
7	22·7	27	21·8	29
8	26·1	24	24·1	26
9	29·7	21	26·8	23
10	33·6	—	29·7	21
11	37·8	—	32·9	19
12	42·1	—	36·5	17
13	46·8	—	40·1	15
14	51·8	—	44·5	14

The computation of the daily task of conversion into sawtimber is based on time measurements of debranching and debarking in unthinned stands, and the computation of the allowable times for cross-cutting is based on the assumption that the stands have been thinned regularly. Debarking and debranching times in thinned stands, however, differ from the mean times in unthinned stands. Debarking time of a tree of a certain diameter in thinned stands is lower than the time of debarking of a tree of the same diameter in an unthinned stand, because the H/D quotient of thinned stands is lower. But debranching time will be higher because of the stronger development of branches in thinned stands.

When table 30 is used for a computation of the day-task in thinned stands, it should be borne in mind that a correction may possibly be necessary for these stands.

The calculations are based, moreover, on normal circumstances. In some cases the daily task has to be corrected, for example, on steeply undulating terrain; or when the trees are difficult to debark. In the latter case it is necessary to take into account the portion of debarking time in total time. When the mean diameter, for example, is 7 inches, debarking time is 63% of total working-time. If it is expected that debarking time will be 40% more than normal, then the total working time will be 25% higher, and the daily task must be reduced by 25%. When the timber is

converted into pulpwood, the debarking time is 30% of total time of felling, debarking time and debranching, so that the daily task should be reduced by 12%.

Labour costs:

The wages can be assumed at an average of R0.50 per day, namely R0.35 paid out as direct wages, and R0.15 for accommodation and rations. The labour costs per minute of actual working time are therefore 0.159c. The computation of labour costs, based on conversion to 8 ft. poles is summarised in table 31.

Table 31.

Labour Costs for Conversion to Poles of a Length of 8 ft.

d.b.h. inches	Working time min./tree	Costs c./tree	Volume cu. ft./tree	Costs c./cu. ft.
4	13.0	2.08	1.5	1.39
5	16.4	2.57	3.4	0.76
6	19.6	3.15	5.5	0.57
7	22.8	3.65	7.9	0.46
8	26.3	4.15	10.7	0.39
9	29.9	4.73	14.3	0.33
10	33.8	5.40	17.8	0.30
11	38.0	6.06	21.8	0.28
12	42.3	6.72	26.0	0.26
13	47.0	7.47	31.0	0.24
14	52.0	8.30	37.0	0.22

The costs of constructing improvised plantation roads have still to be added as well as the costs of direct supervision.

Entirely apart from these time studies the books of 6 saligna plantations were analysed. The actual labour costs differed within limits and were generally considerably higher than those derived from the time studies. The actual costs were:

Plantation 1: 1.2c per cu. ft.
,, 2: 0.4c ,, ,,
,, 3: 0.8c ,, ,,
,, 4: 1.5c ,, ,,
,, 5: 0.4c ,, ,,
,, 6: 0.7c ,, ,,

The mean diameter in these stands was 6.5 inches and on the basis of the data given in table 31 the costs should have been 0.51 per cu. ft. The average of the actual costs was 0.83c or 63% higher.

In part this wide difference was due to the absence of efficiency in the organisation of the work. In any exploitation operations it is not sufficient merely to rationalise the forest labour. This operation will not achieve the desired result, unless it is combined with an efficiently planned system of bookkeeping which in its turn provides an efficient control of production costs.

CHAPTER VIII

ECONOMICS OF SALIGNA PLANTATIONS

1. Production Costs.

Cost figures have been collected in private plantations and augmented by data from the Department of Forestry. Cost of operations which are carried out by piece work, for example, pitting, pruning, felling, primary conversion and transportation are well founded. Other figures are estimates and therefore less reliable.

Land value. The value of the land is related to cost of clearance of scrub, cost of road construction, transportation distance to station or sawmill and soil fertility. The value fluctuates between R12 and R36 per acre and can be fixed at an average of R24 per acre. When a stand has to be established on bare land, costs are high, because the vegetation has to be destroyed by repeated cultivation of the soil. These costs, which comprise the costs of burning of the vegetation, ploughing and harrowing, vary between R8 and R14 per acre. According to figures of the Department of Forestry, the average costs of road construction are R400 per mile. The costs per acre are dependent on the length of the roads per acre. An average length of 1 mile per 100 acres has been recommended for the plantations in Zululand, but the present road intensity in the Transvaal is considerably higher and is estimated at 1 mile per 65 acres. The costs of road construction in Zululand are therefore R4 per acre and in the Transvaal R6 per acre.

Thus approximately 4% of the plantation area is occupied by roads. If the costs of cleaning, preparation of the ground and the cost of road construction are added to the cost of the actually plantable ground, the total land value per planted acre is increased to R42. (The possibility that part of the ground for some reason or other may be unsuitable for planting has been ignored.)

Cost of Establishment: The computation is based on the assumption that planting holes will be made, and an espacement of 9 x 9 ft. used. Cost of plants is taken at R0.8 per 100 plants, the sale price of saligna plants in state nurseries. The cost price of the plants is probably lower, but no reliable figures could be obtained. Holes are made by adults, at piece-rates. Under average conditions 100 holes per day can be made. Planting is usually performed by women and boys, with a daily wage

of R0.30 including rations. It is not usually done as task-work, because planting requires much care. One labourer usually plants 1 acre daily, if the espacement is 9 x 9 ft. In Zululand the cost of planting is higher, because the plants have to be watered. For every 2 planters one woman is employed in watering. The cost of transporting water to the field is approximately R0.30 per day. The costs of establishment are therefore:

		Transvaal	*Zululand*
Plants	R/acre	4.30	4.30
Making of holes	,,	2.70	2.70
Planting	,,	0.30	0.30
Watering	,,	—	0.16
Transportation of water	,,	—	0.30
Direction supervision	,,	0.46	0.52
Total	R/acre	7.76	8.28

Weeding and Blanking.

Cost of weeding is approximately R1.60 per acre. Replacement of plants which have failed is necessary if more than 10% of the plants die. This number of plants varies widely and in Zululand it is higher than in the Transvaal. This calculation assumes that the percentage of trees dying is 15% in the Transvaal and 20% in Zululand. It is also assumed that the original planting hole can be used, that planting and watering take 30% more time and that the cost of direct supervision is 20% of the labour costs. The costs of weeding and blanking are therefore:

		Transvaal	*Zululand*
Weeding	R/acre	1.60	1.60
Plants	,,	0.64	0.86
Planting	,,	0.06	0.08
Watering	,,	—	0.04
Transportation of water	,,	—	0.06
Direct supervision	,,	0.14	0.20
Total	R/acre	2.44	2.84

Regeneration by Coppicing.

The number of shoots per stool has to be reduced to one in 2 or 3 successive operations. Costs vary widely and an assumed average of R4 per acre is used.

Pruning.

Pruning costs are not included in the financial calculations, mainly because pruning is not yet done systematically and also because present prices of sawtimber are valid for timber from trees which have not been pruned.

Felling and subsequent primary conversion.

The costs, analysed in the preceding chapter, are multiplied by 1.5, because the actual costs of felling and other operations are higher than the costs derived from time studies.

Cost of Transportation.

Mining and pulptimber poles are stacked in the stand and transported from there to the station, but sawlogs are usually skidded to the road and loaded there. The average skidding costs are 0.8c per cu. ft., according to cost figures of the Department of Forestry. Transportation is usually undertaken by transport contractors, but in large plantations it is more economical to have a special transport section. The costs charged by the contractors are dependent on the transportation distance. For distances of 6—8 miles, the costs are R0.10 per ton/mile including loading and unloading. When the distance is 20—35 miles, the costs are R0.075 per ton/mile. The calculation will be based on a mean transportation distance of 8 miles, so that the transportation costs are R0.80 per ton. The costs per cu. ft. are dependent on the density of the wood. The costs for sawlogs which are transported immediately after felling are 2.6c per cu. ft. and those for mining-timber and pulpwood, transported after 5—6 weeks, are 1.6c per cu. ft.

Overhead Costs.

Overhead costs are usually charged as a fixed amount per acre. The labour volume, however, is not uniformly distributed over a whole rotation but is concentrated on establishment, in the beginning of the rotation, and on exploitation at the end. It is preferable therefore, to allocate a portion of these overhead costs, namely salaries of managers and administrative staff and office expenses according to the labour volume of the various operations. According to data of the Department of Forestry, these costs for 1957 were 16—18% of direct costs. But as expenditure on managerial and administrative staff did not increase proportionately with investments in new plantations, this percentage is regarded as abnormally low. The percentage in private plantations is at present considerably higher, because the ratio of managing and administrative officers to area of plantation is higher, especially on small plantations. The present calculations will be based on 40%.

The other annual general costs can be charged as a fixed amount per acre:

(1) *Fire Protection.*

The average cost of fire protection is fixed at R0.36 per acre.

(2) *Fire Insurance.*

When an excess of 1% (minimum R200 maximum R2,000) is accepted, and a full cover of the property is required, the premium is R1.50 per R200. The yield table of unthinned stands in the Transvaal gives a volume of 1,390 cu. ft. per acre in site class IV, age 5 years. Because the average stocking is 10% less than full the actual volume is 1,250 cu. ft. per acre. The timber can be insured for a value of 5.5c per cu. ft. so that the average insured value of the normal forest, with a rotation of 10 years, is R68.80 per acre, and the annual premium R0.52 per acre.

(3) *Maintenance of Roads.*

Annual road maintenance cost is R30 per mile, according to data of the Department of Forestry. But it will be necessary to metal these roads every 20 years, entailing an expense of R200 per mile. The annual cost per mile is therefore R40 corresponding to R0.40 per acre per annum in Zululand and R0.62 per acre per annum in the Transvaal.

(4) *Maintenance and Depreciation of Buildings.*

According to figures of the Department of Forestry the capital value of the offices, inspection buildings, outer buildings, nursery buildings, telephone lines and dams is R6 per acre. Annual maintenance and depreciation together have to be fixed at 4% of this value, which is R0.24 per acre.

(5) An amount of R0.20 per acre has to be provided for contingency expenditure.

The total annual general costs are:

		Transvaal	*Zululand*
Fire protection	R/acre	0.36	0.36
Fire insurance	,,	0.52	0.52
Road maintenance	,,	0.62	0.40
Maintenance and depreciation of buildings etc.	,,	0.24	0.24
Estimated overhead costs	,,	0.42	0.34
Contingency	,,	0.20	0.20
Total	R/acre	2.36	2.06

Rate of Interest.

In European countries, the rate of interest, adopted for forests, is usually the same as the rate of interest of government bonds, because investment in forest plantations is regarded as being accompanied by low financial risks. The production of saligna timber in South African plantations, however, is practised as a commercial undertaking, for which money is borrowed. An appropriate rate of interest of 6% has been adopted.

2. Yields.

The yield tables for the Transvaal and Zululand give volume yields for unthinned and thinned stands with a degree of stocking of 100. Because of disease, wind damage etc., the actual degree of stocking will be lower than 100 and the volumes have been reduced by 10%. To obtain the money yield per acre, the volume yield was multiplied by the stumpage value per cu. ft.

Sawtimber. The price of sawlogs, with a minimum top-diameter of 5.5 inches and a minimum length of 6—8 ft. is R0.10 per cu. ft. in the Transvaal; 8.3c per cu. ft. in Zululand, both delivered at sawmill. Above this top diameter there is no relation between diameter and price.

Mining Timber.

The following sizes are used by the mines:

length	6 ft.,	topdiameter	1½—2½	inches
,,	6 ,,	,,	4 —5	,,
,,	8 ,,	,,	2½—7	,,
,,	10 ,,	,,	3 —4	,,
,,	12 ,,	,,	4 —5	,,

8 foot poles with a topdiameter of 3½—6 inches are in greatest demand. The price of mining timber during the year 1958 was R3 per ton, f.o.r. in Zululand; R4.35 per ton in Eastern Transvaal; and R3.70—R4 per ton in Northern Transvaal. This price refers to timber having a moisture content of approximately 25% (as commonly defined in S.A. Mining Timber practice).

Pulpwood.

This timber is produced in poles with a length of 6—8 ft. and a top diameter of 2.5—14.0 inches. The price of pulpwood, f.o.r. is R2.75 per ton, both in Zululand and the Eastern Transvaal.

Telephone, Transmission and Scaffolding Poles.

Telephone and transmission poles are supplied in lengths of 18, 20, 24, 30, 35 and 42 feet with top diameters of 3½—4½, 4½—6 and 6½—8½ inches. The length of scaffolding poles is 9—30 feet, with a top diameter 2½—3½ inches. The price of telephone poles in the N. Transvaal is R6.30—R7.20 per ton free on rail, and of scaffolding poles it is R4.70—R5.50 per ton f.o.r. There is a limited export market for transmission poles. The price, R0.25 per cu. ft., is higher than that for poles locally used, primarily because of the very high quality of the material. Poles sold on the home market only fetch R0.125 per cu. ft. at sawmill.

Investigations by Banks (1955) have shown that the strength of saligna timber is not satisfactory for telephone and transmission poles, and it is probable that the species will not be used for this market.

Present production is of little importance and the manufacture of this class of material has therefore been omitted from the study.

Plantations producing saligna timber in short rotation in N. and E. Transvaal supply mainly mining timber, so that it is permissable to base the calculations on a price for mining timber of R4 per ton or R0.08 per cu. ft. In Zululand the price of mining timber is lower, because the transportation distance is greater and there is only a small difference between the price of mining timber and pulpwood. The price of pulpwood can be taken at R0.06 per cu. ft.

The economic aspects of saligna plantations will be discussed in the following sections. The symbols, which will be used are:

E_t = nett-value of the final crop (gross-value minus cost of felling, primary conversion and transportation).

D_a = nett-value of the thinning at a year.

C = cost of establishment.

B = capitalised annual general costs.

p = rate of interest.

CP_r = relative cost price.

t = rotation.

G_{vt} = land expectation value at t years.

G = market value of the land.

O_{nt} = profit per acre of the normal forest.

O_{pt} = profit per acre of the periodic forest.

V_{nkt} = cost value of the growing stock of the normal forest.

V_{nvt} = expectation value of the growing stock of the normal forest.

3. Espacement.

The influence of espacement on volume yield and mean diameter of the stand has been discussed in chapter IV and it was shown that volume yield increases with increasing number of stems per acre. Cost of establishment and cost of felling and subsequent primary conversion per cu. ft., however, also increase. It must now be ascertained whether the higher volume yield balances the increased cost of production. The cost figures can be derived from the foregoing sections; it is assumed that overhead costs per acre do not change when costs of establishment and felling increase, and in this comparison they are omitted. The computation of cost of planting is based on a rotation of 7 years (h_{dom} = 80 ft.) for the Transvaal and 10 years (h_{dom} = 100 ft.) for Zululand. The result is given in table 32.

The financial yield minus cost of felling and primary conversion, transportation and cost of planting is approximately the same for stands with a varying number of stems per acre. A spacing of less than 9 x 9 ft. cannot be recommended for the independent saligna timber producer. The financial yield does not decrease, even for the first or second generation coppice, originated from the planted stand. The situation is different for those plantations associated with the pulp industry for which an espacement of 7 x 7 ft. is recommended.

Table 32

Financial Yield for Stands of Various Number of Stems per Acre

Spacing (feet)	Number of stems per acre	Yield		Cost of felling and primary conversion		Cost of establishment (including blanking) R/acre	Cost of cleaning of coppice R/acre	Mean cost of establishment R/acre	Multiplier 1 . op^t (p – rate of interest t – rotation)	Cost of establishment x 1 . op^t	Money yield-cost of felling and primary conversion-cost of establishment-cost of transportation (Columns 4, 6, 11)
		Cu. ft./acre	R/acre (minus cost of transportation	c per cu. ft.	R/acre						
1	2	3	4	5	6	7	8	9	10	11	12
Transvaal (Rotation 7 years, volume yield corresponds with h_{dom} = 80 feet).											
7×7	889	2438	156·0	1·16	28·3	17·2	6·6	10·2	1·504	15·3	112·4
8×8	681	2287	146·4	1·00	22·9	13·6	5·0	7·8	1·504	11·7	111·8
9×9	538	2184	139·8	0·90	19·6	11·0	4·0	6·4	1·504	9·6	110·6
10×10	436	2110	135·0	0·81	17·1	9·2	3·2	5·2	1·504	7·8	110·1
11×11	360	2054	131·4	0·73	15·0	8·0	2·6	4·4	1·504	6·6	109·8
12×12	303	2013	128·8	0·65	13·1	7·0	2·2	3·8	1·504	5·7	110·0
Zululand (Rotation 9 years, volume yield corresponds with h_{dom} = 100 feet)											
7×7	889	4500	198·0	0·90	40·5	17·2	6·6	10·2	1·791	18·3	139·2
8×8	681	4258	187·4	0·75	31·9	13·6	5·0	7·8	1·791	14·0	141·5
9×9	538	4092	180·0	0·67	27·4	11·0	4·0	6·4	1·791	11·5	141·1
10×10	436	3974	174·8	0·61	24·2	9·2	3·2	5·2	1·791	9·3	141·3
11×11	360	3886	171·0	0·55	21·4	8·0	2·6	4·4	1·791	7·9	141·7
12×12	303	3819	168·0	0·51	19·5	7·0	2·2	3·8	1·791	6·8	141·7

4. Rotation.

A. *Rotation for Production of Mining Timber and Pulpwood.*

In considering length of rotation it is important to distinguish between various types of rotation, particulars of which follow:

(i) *Rotation of the Highest Volume Yield.*

Production of the maximum possible volume is the main consideration and the rotation coincides with the age of culmination of the mean annual increment. The following table gives the calculated rotation for different site qualities:

Table 33.

Rotation of the Highest Volume Yield in the Transvaal and Zululand.

	Transvaal	Zululand
Site index III	10.0	10.5 years
Site index IV	11.0	11.5 years
Site index V	11.5	13.5 years
Site index VI	12.5	16.5 years

This rotation is of value when there is no relationship between breast high diameter and wood value per cubic foot. If such exists then it would be preferable to consider the rotation of the highest nett money yield.

(ii) *Rotation of the Highest Nett Money Yield.*

The nett income for different ages is calculated and the rotation coincides with the age at which the nett income culminates. The formula is:

$$\text{Mean nett yield} = \frac{E_t + [D] - c}{t}$$

Because of the decrease in production after some generations of coppice a cycle comprising one planted generation followed by two coppice generations was used in the calculations the results of which are given in table 34.

Table 34.

Rotation of the Highest Nett Yield in the Transvaal and Zululand.

	Transvaal	Zululand
Site index III	11	12
Site index IV	12	14
Site index V	13	16
Site index VI	14	17—18

The rotation of the highest nett yield is longer than the rotation of the highest volume yield because the nett value per cu. ft., increases with increasing diameter.

No regard is paid to the amount of capital invested, so that the rotation of the highest nett yield does not give the highest profit per acre or the highest rate of interest. The type of rotation cannot be recommended for commercial undertakings.

From the standpoint of the producer, the financial rotation is preferable.

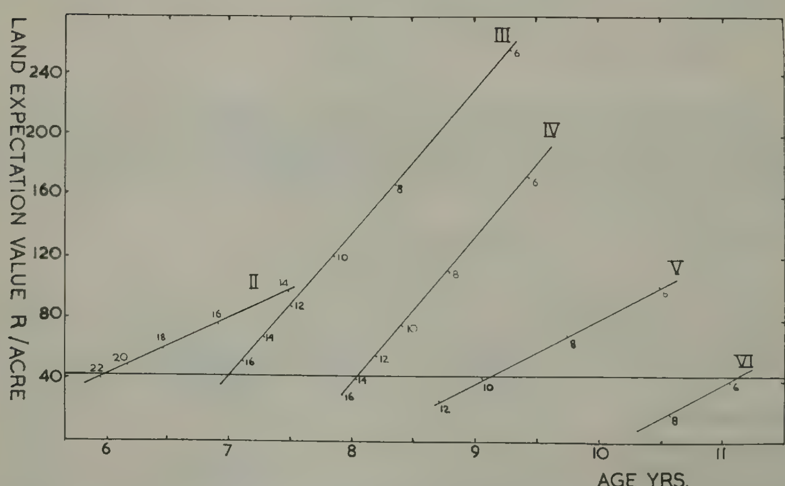
(iii) *Financial rotation of the highest rate of earned interest.*

This rotation is obtained from the computation of the age which gives the highest rate of interest. A fixed market value of the soil has to be assumed. The equation is:

$$(G + B)\ (1.op^{t} - 1) + C\ 1.op^{t} = E_{t} + [D_{a}\ 1.op^{t-a}] \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

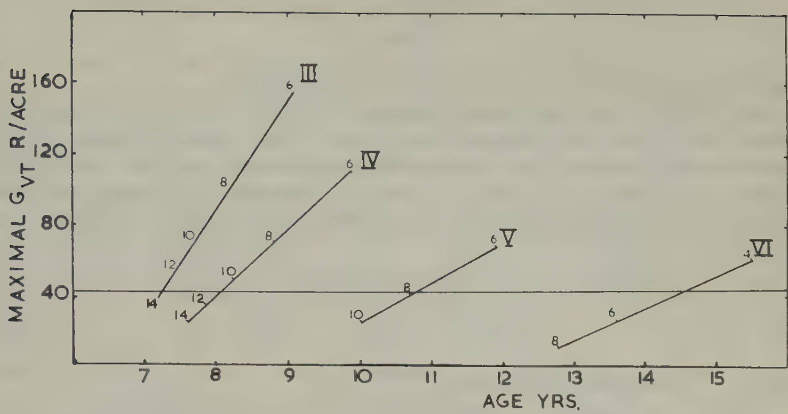
The value of t for which p is maximal has to be calculated. The maximal land expectation value and corresponding ages for a series of rates of interest have to be computed. These expectation values are plotted against the corresponding ages and a smooth curve is fitted to the points. The rotation of the highest rate of interest is the age for which the maximal land expectation value is equal to the market value of the land. The result of the computations is shown in figs. 12 and 13 and in table 35.

Figure 12.



Rotation for the highest earned rate of interest in the Transvaal.

Figure 13.



Rotation for the highest earned rate of interest in Zululand.

Table 35.

Financial Rotation of the Highest Rate of Earned Interest in the Transvaal and Zululand and Corresponding Rate of Interest.

	Transvaal		Zululand	
	Rotation (Years)	Rate of Interest (%)	Rotation (Years)	Rate of Interest (%)
Site index II	6.0	22.0	—	—
Site index III	7.0	17.5	7.5	12.5
Site index IV	8.0	13.5	8.5	10.5
Site index V	9.0	10.0	11.0	7.5
Site index VI	11.0	6.0	14.3	5.0

(iv) *Financial rotation of the highest land expectation value.*

The financial rotation of the highest rate of interest can be used where adequate land for tree growing is readily obtainable. The economic approach can change in industrialised areas where only a limited area of land is available. Here the entrepreneur will try to obtain the highest rate of return from the limited area of land, and he will aim at the highest profit per acre. The land expectation value is a suitable standard of profit, because it is equal to the market value plus capitalised profit.

The land expectation value is derived from Faustmann's formula:

$$G_{vt} = \frac{E_t + [D_a.1.op^{t-a}] - C.1.op^t}{1.op^t - 1} - B \quad \dots \dots \dots \dots \dots \quad (3)$$

Equation (3) is, of course, identical to equation (2).
That age, which puts the land expectation value at a maximum is the financial rotation of the highest land expectation value. Formula (3) has to be modified, because the costs of establishment are not constant. If the cost of planting is C_1, and the cost of cleaning of coppice in second and third generation C_2, the cost of establishment must be charged with an amount:

$$\frac{C_1.1.op^{3t} + C_2\,(1.op^{2t} + 1.op^t)}{1.op^{3t} - 1}$$

Formula (3) becomes therefore:

$$G_{vt} = \frac{E_t + [D_a.1.op^{t-a}]}{1.op^t - 1} - \frac{C_1.1.op^{3t} + C_2\,(1.op^{2t} + 1.op^t)}{1.op^{3t} - 1} - B \quad (4)$$

An example of the computation for site class IV in the Transvaal, is given in table 36, while table 37 gives the value for maximal land expectation value. The financial rotation of the highest land expectation value is given in table 38.

Table 36.

Computation of the Financial Rotation of the Highest Land Expectation Value in the Transvaal, Site index IV.

Age	Gross-value of final crop (R/acre)	Cost of felling and primary conversion (R/acre)	Overhead costs on felling etc. (R/acre)	Costs of transportation (R/acre)	Nett value of final crop (R/acre)	Capitalisation factor $\frac{1}{1.op^t - 1}$	Capitalised cost of planting (R/acre)	Gross land expectation value (R/acre)	Capitalised annual general costs (R/acre)	Nett land expectation value (R/acre)
4	62.64	13.06	5.22	12.52	31.84	3.817	44.20	81.00	39.34	38.0
6	139.68	19.16	7.66	27.94	84.92	2.392	32.40	174.62	39.34	131.4
8	215.28	24.44	9.78	43.06	138.00	1.684	26.60	209.86	39.34	166.6
10	281.52	28.80	11.52	56.30	184.90	1.264	23.20	214.70	39.34	171.2
12	336.24	31.88	12.76	67.24	224.36	0.988	21.00	204.96	39.34	161.2
14	382.32	34.54	13.82	76.46	257.50	0.793	19.60	189.12	39.34	145.2
16	418.32	37.04	14.82	83.66	282.80	0.649	18.40	169.68	39.34	125.8

The result of the computations of the maximal land expectation value is summarised in table 37.

Table 37

Maximal land expectation value in the Transvaal and Zululand
(R/acre)

Site Index	Transvaal					Zululand			
	II	III	IV	V	VI	III	IV	V	VI
Age									
4	174·8	101·8	38·0	–10·8	–48·2	78·2	27·2	14·4	–68·2
6	303·6	208·0	131·4	59·2	3·6	128·2	79·8	30·2	–15·4
8	347·6	249·2	166·6	92·8	29·0	147·8	101·8	53·0	6·2
10	—	251·4	171·2	100·8	39·2	150·8	106·8	62·6	16·2
12	—	232·4	161·2	96·8	40·4	141·4	102·6	65·0	21·0
14	—	—	145·2	87·0	37·2	—	93·6	61·8	22·0
16	—	—	125·8	75·8	30·8	—	—	56·0	21·0

Table 38.

Financial Rotation of the Highest Land Expectation Value.
(years)

	Transvaal	Zululand
Site index III	9.0	9.1
Site index IV	9.3	9.8
Site index V	10.3	11.8
Site index VI	11.5	14.0

The rotation of the highest rate of interest is shorter than the rotation of the highest land expectation value when the earned rate of interest is higher than the fixed rate of interest, and vice versa.

The financial rotation of the highest rate of interest is recommended for saligna plantations in South Africa. In some districts, however, the rotation of the highest land expectation value is preferable, because of a shortage of land within reasonable distance of a railway station, for example, the districts Tzaneen-Duiwelskloof and Kwambonambi-Mtubatuba.

The relative cost price:

The relative cost price is found when the gross value of the yield is multiplied by a factor cp_r, giving a land expectation value equal to the market value of the land. The equation is:

$$\frac{Cp_r.\ (E_t + [D_a.1.op^{t-a}]) - C.1.op^t}{1.op^t - 1} - B = G \quad \dots \dots \dots \dots \quad (5)$$

It follows that for thinned stands:

$$Cp_r = \frac{(G + B)\ (1.op^t - 1) + C.1.op^t}{E_t + [D_a.1.op^{t-a}]} \quad \dots \dots \dots \dots \dots \dots \quad (6)$$

and for unthinned stands:

$$Cp_r = \frac{(G + B)\ (1.op^t - 1) + C.1.op^t}{E_t} \quad \dots \dots \dots \dots \dots \dots \quad (7)$$

The relative cost price at t years is therefore equal to the ratio,

$$\frac{\text{cost value of the stand at t years.}}{\text{gross value of the stand at t years.}}$$

The relative cost price, corresponding to the financial rotation of the highest rate of interest is:

Table 39.

Relative Cost Price in the Transvaal and Zululand.

	Transvaal		Zululand	
	Rotation (Years)	Relative cost price (%)	Rotation (Years)	Relative cost price (%)
Site index II	6	55.0	—	—
Site index III	7	59.2	7	74.3
Site index IV	8	65.7	8	80.4
Site index V	9	77.9	11	89.9
Site index VI	11	100.9	14	114.1

B. *Rotation in saw timber plantations.*

At present there are in South Africa only a few plantations, producing saligna saw timber and they are closely connected with the sawing industry, e.g. South African Forest Investments, S.A. General Investment and Trust Co. and Westfalia Estate. These plantations supply the sawmills with raw material. The rotation has to be based preferably on the absolute cost price of the timber per cu. ft. For these calculations it is necessary to use a yield table for heavy thinning up to higher ages than required for other end products. This yield table is at present available only for site classes III and IV in Transvaal plantations.

It is assumed that timber obtained from final stand and thinnings with a top diameter below 5½ inches will be sold as mining timber and the thicker timber as sawlogs. The object or management in these stands is the production of saw timber, and the mining timber obtained from thinnings is regarded as a by-product, the value of which has to be deducted from the total cost of production.

The contribution of cost of planting to the total cost will be based on the assumption that the stand is replanted after clear felling since regeneration by means of coppicing is not desirable for stands producing saw timber.

The cost of transportation of saw timber exceeds that of mining timber, because the moisture content of the timber is higher. Also the cost of skidding, estimated at 0.83c per cu. ft. including direct supervision has to be charged under this heading. The result is summarised in table 40.

Table 40.

Production Costs per cu. ft. Roundwood in Saw timber Plantations.
(Site index IV, rotation 13 and 18 years.)

Age		13	18
Cost of planting (incl. overhead costs) ...	R/acre	30.46	40.76
Soil rent*	,,	47.58	77.86
Annual general costs	,,	44.58	72.94
Cost of felling and primary conversion (incl. overhead costs)	,,	41.76	73.40
Skidding and transportation	,,	125.10	211.74
Brushpiling	,,	3.00	3.00
Total	,,	292.48	479.70
Yield of mining timber	,,	106.74	131.20
Production costs	,,	185.74	348.50
Volume yield saw timber from thinnings cu. ft./acre		757	1948
Final crop cu. ft.		2408	2721
Total cu. ft./acre		3165	4669
Cost price c/cu. ft.		5.87	7.46

* Soil rent is ordinarily defined as the interest of land expectation value. In these calculations however, soil rent is calculated as O.op x G.

The cost price per cu. ft., roundwood is, on a rotation of 18 years, 1.59c or 27% higher than on a rotation of 13 years.

The cost price per cu. ft. of sawn timber, excluding costs of sawing and seasoning, is 15.6c at a rotation of 13 years and 19.0c at a rotation of 18 years.

In consequence of the higher saw recovery from stems of greater diameter, the difference in cost price has decreased from 27% to 21.8%. Nevertheless, the absolute cost price per cu. ft. of sawn timber is 3.4c higher at a rotation of 18 years than at a rotation of 13 years. It is true that the quality of the timber is better when the trees are older, because there are fewer knots and the wood is denser, but it seems doubtful whether this improved quality compensates for the higher production costs. The price per cu. ft. roundwood, delivered to sawmill, is not related to the diameter of the tree. The following objections can be raised against this price policy:

1. Saw recovery increases with increasing diameter.
2. The width of the knot-free band of timber is generally greater when the diameter of the trees is higher.
3. A bigger diameter usually connotes a greater age, and the timber of older trees is stronger than that of younger trees.

As long as the present price policy remains unchanged, a rotation of 12—14 years for saw timber stands is more profitable than a longer rotation of 18—20 years.

4. **Profit and cost analysis in the normal forest.**

The normal forest, with an area of t acres, when t = the number of years of the rotation, consists of t age classes of 1 acre.

The entrepreneur's annual gain per acre in the normal forest is the difference between mean annual income and mean annual expenditure. The annual income is: $E_t + [D_a]$.

The annual expenditure is:

cost of planting	c
general annual costs	tb
soil rent	o.op.G.t
interest of the growing stock	$o.op.V_{nt}.t$

The entrepreneur's annual gain per acre therefore is:

$$O = \frac{E_t + [D_a] - (c + tb + o.op.G.t + o.op.V_{nt}.t)}{t} \quad \ldots \ldots \quad (8)$$

The formula for the expectation value of the growing stock of the normal forest per acre is:

$$V_{nvt} = \frac{E_t + [D_a] - (c + tb)}{t.o.op} - G_{vt} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (9)$$

so that:

$$O_{nt} = O.Op\ (G_{vt} + V_{nvt}) - O.Op\ (G + V_{nt}) \ldots \ldots \ldots \ldots \ldots \quad (10)$$

In appraising the value of the growing stock of the normal forest, V_{nt}, there is a choice between expectation value and cost value. The latter is preferable, because the expectation value consists of cost value plus estimated capitalised gain to the entrepreneur. The interest of this capitalised profit cannot be regarded as a cost element.

When cost value is used, the result is:

$$O_{nt} = o.op\ (G_{vt} - G) + o.op\ \ (V_{nvt} - V_{nkt}) \ldots \ldots \ldots \ldots \ldots \quad (11)$$

In a periodic forest, that is a forest consisting of one age class with an area of t acres, the profit per acre, realised at the end of the rotation is:

$$E_t + [D_a.1.op^{t-a}] - ((G + B)\ (1.op^t - 1) + c.1.op^t) \ldots \ldots \ldots \quad (12)$$

Multiplication by the factor $\dfrac{o.op}{1.op^t - 1}$ gives the corresponding entrepreneur's gain per annum:

$$O_{pt} = \frac{(E_t + [D_a.1.op^{t-a}] - c.1.op^t)\ o.op}{1.op^t - 1} - \frac{(G + B\ (1.op_t - 1)\ \ o.op}{1.op^t - 1} \quad (13)$$

Substitution of formula (2) gives:

$$O_{pt} = (G_{vt} - G)\ o.op \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (14)$$

Comparison of formulae (11) and (14) shows that the entrepreneur's annual gain from the normal forest is greater than that of the periodic forest. The difference, o.op $(V_{nvt} - V_{nkt})$ is equal to the interest of the entrepreneur's capitalised gain, invested in the growing stock of the normal forest.

The formula for the cost value of the growing stock of the normal forest is:

$$V_{nkt} = \frac{(G + B + c)\ (1.op^t - 1)}{t.o.op} - (G + B) \quad \dots\ \dots\ \dots\ \dots \quad (15)$$

Substitution of (2), (9) and (15) in equation (11) gives:

$$O_{nt} = \frac{(G_{vt} - G)\ (1.op^t - 1)}{t} \quad \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots \quad (16)$$

The result of the computations is given in table 41.

Table 41.

Annual Entrepreneur's Gain in Unthinned Mining Timber and Pulpwood Stands.

			Transvaal				
		Normal forest				Periodic forest	
Site Index	Rotation Years	Yield R/acre	Costs R/acre	O_{nt} R/acre	G_{vt} R/acre	G R/acre	O_{pt} R/acre
II	6	40.56	22.30	18.26	303.6	42.0	15.70
III	7	33.78	20.00	13.78	233.8	42.0	11.50
IV	8	26.92	17.68	9.24	166.6	42.0	7.48
V	9	19.80	15.42	4.38	99.2	42.0	3.44
VI	11	13.52	13.62	0.10	40.6	42.0	0.08
			Zululand				
III	7	27.54	20.46	7.08	140.8	42.0	5.92
IV	8	22.64	18.20	4.44	101.8	42.0	3.58
V	11	18.16	16.32	1.84	64.6	42.0	1.36
VI	14	12.74	14.54	1.80	22.0	42.0	1.20

The entrepreneur's annual gain in heavily thinned stands, producing sawing timber in a normal forest is:

Site index III, 12 years, R19.50 acre/annum.
Site index IV, 13 years, R12.48 acre/annum.

The entrepreneur's gain in these plantations cannot, however, be compared directly with that of unthinned stands, because both the rotation and the mean volume per acre are different.

Distribution of costs.

The production costs per acre of unthinned stands, at t years are:

$$(G + B)\ (1.op^t - 1) + c.1.op^t \quad \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots \quad (17)$$

The actual annual expenditure in normal forest is:

$$O.op\ (G + B)\ t + c \quad \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots \quad (18)$$

The annual interest, involved in the production is:

$$(G + B)\ (1.op^{t} - 1) + c.1.op^{t} - o.op\ (G + B).\ t - c =$$
$$(G + B + c)\ (1.op^{t} - 1) - t.o.op\ (G + B).$$

Multiplication by the factor 1/t gives the costs per acre. The cost of planting, felling an primary conversion, and annual general costs are split up into direct labour costs and costs of supervision and administration. The result is given in table 42 and fig. 14.

Figure 14.

Cost distribution in the normal forest.

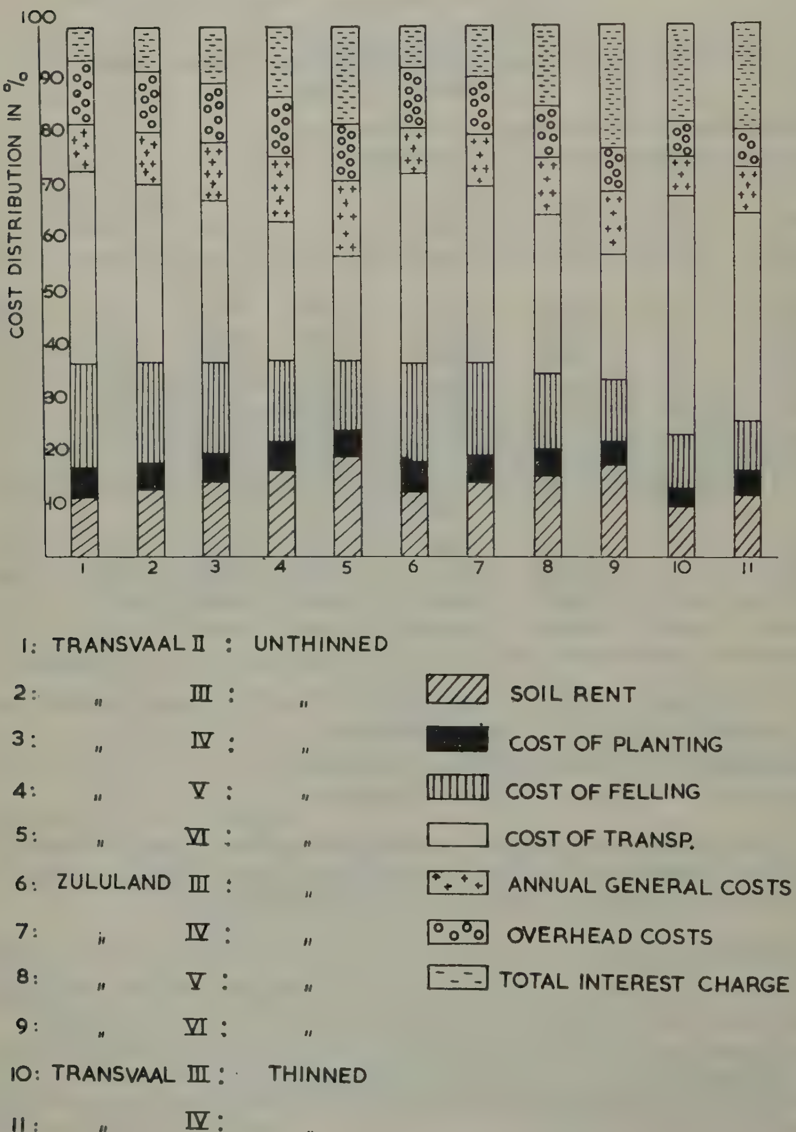


Table 42.

Distribution of Costs in the Normal Forest.

Production goal	Mining timber and pulpwood									
Region	Transvaal									
Site index	II		III		IV		V		VI	
Age	6		7		8		9		11	
	R/ acre	%	R/ acre	%	R/ acre	%	R/ acre	%	R/ acre	%
Soil rent	2.52	11.3	2.52	12.6	2.52	14.3	2.52	16.3	2.52	18.5
Cost of planting	1.14	5.1	1.00	5.0	0.88	5.0	0.80	5.2	0.68	5.0
Cost of felling & primary conversion	4.50	20.2	3.78	18.9	3.06	17.3	2.40	15.6	1.78	13.1
Cost of transportation	8.12	36.4	6.74	33.7	5.36	30.3	3.98	25.8	2.70	19.8
Annual general costs	1.94	8.7	1.94	9.7	1.94	11.0	1.94	12.6	1.94	14.2
Cost of supervision & administration	2.68	12.0	2.34	11.7	2.00	11.3	1.70	11.0	1.40	10.3
Total interest charges	1.40	6.3	1.68	8.4	1.92	10.8	2.08	13.5	2.60	19.1
Total	22.30	100.0	20.00	100.0	17.68	100.0	15.42	100.0	13.62	100.0

Production goal	Mining timber and pulpwood							
Region	Zululand							
Site index	III		IV		V		VI	
Age	7		8		11		14	
	R/acre	%	R/acre	%	R/acre	%	R/acre	%
Soil rent	2.52	12.3	2.52	13.8	2.52	15.4	2.52	17.3
Cost of planting	1.06	5.2	0.94	5.2	0.72	4.4	0.60	4.1
Cost of felling & primary conversion	3.84	18.8	3.14	17.3	2.38	14.6	1.70	11.7
Cost of transportation	7.34	35.9	6.06	33.2	4.86	29.8	3.40	23.4
Annual general costs	1.72	8.4	1.72	9.5	1.72	10.5	1.72	11.8
Cost of supervision & administration	2.30	11.2	1.98	10.9	1.58	9.7	1.24	8.5
Total interest charges	1.68	8.2	1.84	10.1	2.54	15.6	3.36	23.2
Total	20.46	100.0	18.20	100.0	16.32	100.0	14.54	100.0

Production goal	Saw Timber			
Region	Transvaal			
Site index	III		IV	
Age	12		13	
	R/acre	%	R/acre	%
Soil rent	2.52	9.5	2.52	11.2
Cost of planting	0.84	3.2	1.02	4.5
Cost of felling & primary conversion	2.64	10.0	2.08	9.5
Cost of transportation	11.86	44.8	8.84	39.3
Annual general costs	1.94	7.3	1.94	8.6
Cost of supervision & administration	1.72	6.5	1.52	6.8
Total interest charges	4.96	18.7	4.58	20.4
Total	26.48	100.0	22.50	100.0

5. **Influence of price and cost changes on land expectation value.**

The foregoing calculations refer to present production costs and present timber prices. Changes in wages and prices affect the land expectation value and profit. Moreover the transportation distance or productivity of the labour in a given plantation can be above or below the average. It is desirable, therefore, to compute the land expectation value for prices and costs which are a certain percentage higher or lower than average.

Calculations were carried out for the yield tables for unthinned stands in the Transvaal and Zululand and a rotation of 8 years for all site classes.

(a) *Influence of timber prices.*

Land expectation value for timber prices which are respectively 10 and 20% above and below present prices is given in table 43.

Table 43

Land expectation value for changed timber prices
(R/acre)

Region	Transvaal					Zululand			
Site Index	II	III	IV	V	VI	III	IV	V	VI
—20%	224·4	153·2	94·2	41·6	–3·8	71·2	40·8	7·8	–23·0
—10%	286·0	201·2	130·4	67·2	12·6	109·4	71·2	30·4	–8·4
+10%	409·2	297·2	202·8	118·4	45·4	186·0	132·4	75·4	35·4
+20%	470·8	345·2	239·0	144·0	61·8	224·2	162·8	98·0	50·0

(b) *Influence of cost of planting.*

Table 44 gives land expectation value assuming that costs of planting are respectively 25 and 50% above and below the average costs.

Table 44

Land expectation value for changed cost of planting
(R/acre)

Region	Transvaal					Zululand			
Site Index	II	III	IV	V	VI	III	IV	V	VI
+50%	338·0	243·6	161·0	87·2	19·4	137·8	91·8	43·0	–3·8
+25%	342·8	248·4	165·8	92·0	24·2	142·8	96·8	48·0	1·2
—25%	352·4	258·0	175·4	101·6	33·8	152·8	106·8	63·0	11·2
—50%	357·2	262·8	180·2	106·4	38·6	157·8	111·8	68·0	16·2

(c) *Influence of annual general costs.*

Land expectation value for general annual costs which are 25 to 50% higher and lower is given in table 45.

Table 45

Land Expectation Value for Changed Annual General Costs
(R/acre)

Region	Transvaal					Zululand			
Site Index	II	III	IV	V	VI	III	IV	V	VI
+50%	331·2	232·8	150·2	76·4	12·6	133·4	87·4	38·6	–8·2
+25%	339·4	241·0	158·4	84·6	20·8	140·6	94·6	43·8	–1·0
—25%	355·8	257·4	174·8	101·0	37·2	154·8	109·0	60·0	13·4
—50%	364·0	265·6	183·0	109·2	45·4	162·0	116·2	71·4	20·6

(d) *Influence of cost of felling and subsequent primary conversion.*

If these costs are 25 and 50% higher or lower, the land expectation value is given in table 46.

Table 46

Land expectation value for changed cost of felling and related operations
(R/acre)

Region	Transvaal					Zululand			
Site Index	II	III	IV	V	VI	III	IV	V	VI
+50%	336·0	239·6	158·2	86·0	23·8	172·0	93·4	47·4	0·6
+25%	341·8	244·4	162·4	89·4	26·4	177·0	97·6	50·2	3·4
—25%	353·4	254·0	170·8	96·2	31·6	187·0	106·0	55·8	9·0
—50%	359·2	258·8	175·0	98·6	34·2	192·0	110·2	58·6	11·8

(e) *Influence of cost of supervision and administration.*

Land expectation value is computed for overhead costs of 20, 30 and 50 and 60% of the direct labour costs.

Table 47

Land expectation value for changed overhead costs
(R/acre)

Region	Transvaal					Zululand			
Site Index	I	III	IV	V	VI	III	IV	V	VI
60%	331·4	234·8	153·8	81·4	19·2	133·0	88·6	41·2	–3·8
50%	339·6	242·0	160·2	87·2	24·2	140·4	95·2	47·0	1·2
30%	355·6	256·4	173·0	98·4	33·8	155·0	108·4	58·8	11·2
20%	363·8	263·6	179·4	104·2	38·8	162·2	114·8	64·4	16·0

(f) *Influence of transportation distance.*

The land expectation value is calculated for a transportation distance of 5, 10, 15, 20 and 25 miles. The costs of transportation per cu. ft. per mile decrease with increasing distances, because the cost of loading and unloading are relatively lower. The computation of the cost of transportation is based on the following costs per cu. ft. per mile.

distance 5 miles: costs, incl. loading & unloading: R0.00210 per cu. ft. per mile.
distance 10 miles: costs, incl. loading & unloading: R0.00194 per cu. ft. per mile.
distance 15 miles: costs, incl. loading & unloading: R0.00180 per cu. ft. per mile.
distance 20 miles: costs, incl. loading & unloading: R0.00164 per cu. ft. per mile.
distance 25 miles: costs, incl. loading & unloading: R0.00150 per cu. ft. per mile.

The corresponding value is given in table 48.

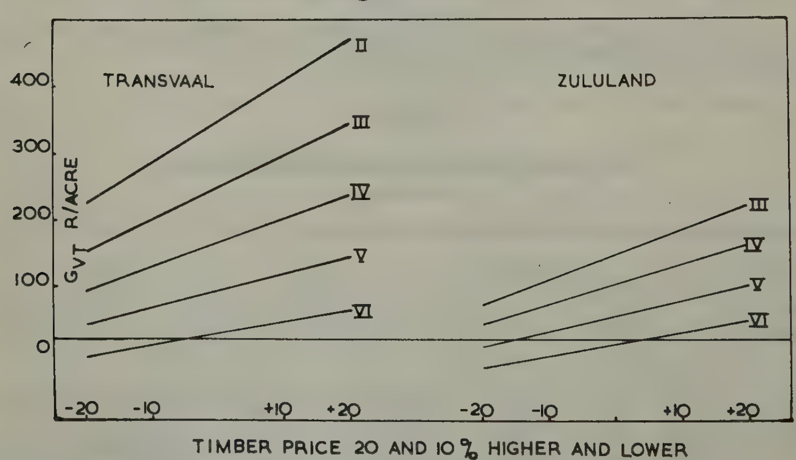
Table 48

Land expectation value for variable transportation distances
(R/acre)

Region	Transvaal					Zululand			
Site Index	II	III	IV	V	VI	III	IV	V	VI
Miles									
5	390·0	282·2	191·4	110·4	40·4	182·8	129·8	73·6	19·6
10	321·4	228·8	151·2	81·8	22·0	126·0	84·6	40·2	–2·0
15	262·8	183·2	116·6	57·6	6·4	77·6	45·8	11·6	–20·6
20	218·0	148·4	90·4	38·8	–5·6	40·6	16·4	–10·2	–34·8
25	181·0	128·6	68·6	23·4	–15·4	9·8	–8·0	–28·2	–46·4

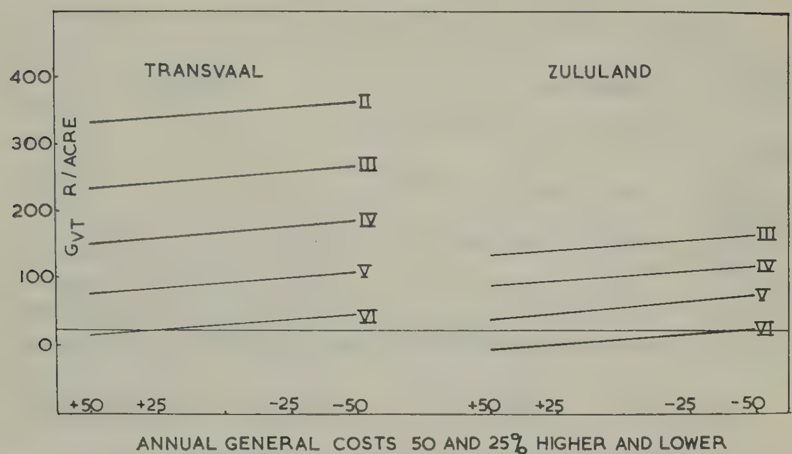
The influence of changed prices and costs is reproduced also in figures 15, 16, 17, 18, 19 and 20.

Figure 15.



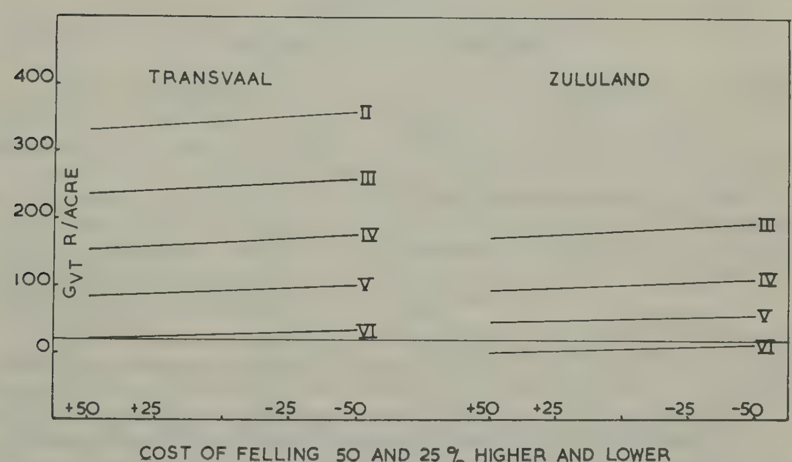
Land expectation value for changed timber prices.

Figure 16.



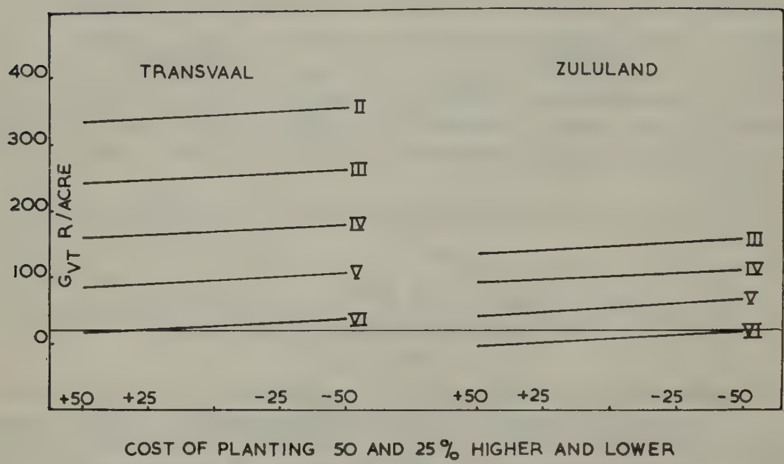
Land expectation value for changed cost of planting.

Figure 17.



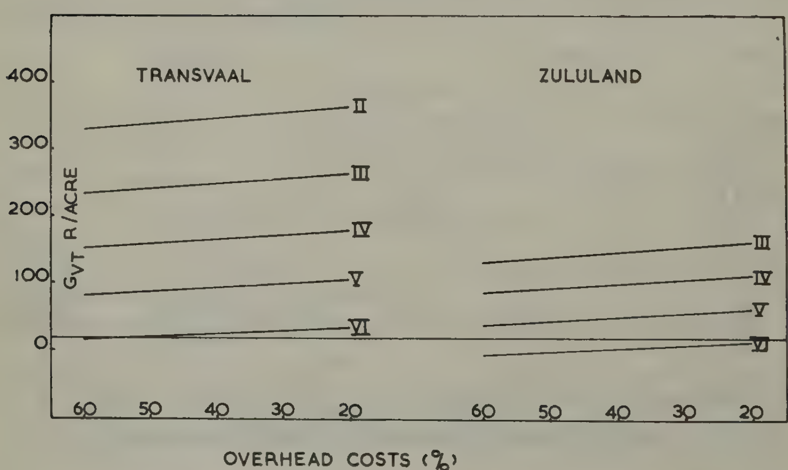
Land exepctation value for changed annual general costs.

Figure 18.



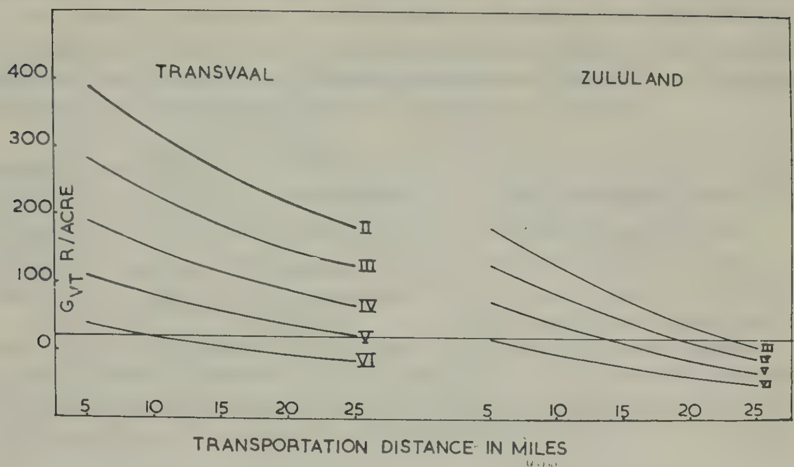
Land expectation value for changed cost of felling and related operations.

Figure 19.



Land expectation value for variable overhead costs.

Figure 20.



Land expectation value for variable transportation distance.

These figures immediately show the level of costs and prices just giving profitable production, that is, when land expectation value exceeds the market value of the land. For example, figure 20 shows that production in site class V in the Transvaal is still profitable when transportation distance is less than 21 miles. In site class VI, however, transportation distance must be less than 5 miles for production to be profitable.

CHAPTER IX

SOCIO-ECONOMIC ASPECTS OF TIMBER PRODUCTION IN SALIGNA PLANTATIONS

Bosman (1956) estimates the volume production of saligna plantations in South Africa at 43.4 million cu. ft. for the year 1955. This corresponds to a mean increment of 180 cu. ft. per acre per annum.

Van Eck (1955) has taken all Eucalyptus species together and estimates their mean increment at 250 cu. ft. per acre per annum. When the increment of the slow-growing Eucalyptus species is 64% of that of saligna (Bosman 1956) the estimate of Van Eck works out at 284 cu. ft. per acre per annum. Total increment is then 68.6 million cu. ft. i.e., 58% more than the estimate of Bosman.

The total annual increment can also be estimated from the yield tables. The mean site index of the plantations in the district Kwambonambi-Mtubatuba is approximately IV, but the site index of plantations north of Mtubatuba, with less precipitation, is considerably lower. The mean site index in Zululand, therefore, will be approximately V. The mean site index of the sample plots laid out in the Transvaal is IV, but there are a number of plantations situated in districts of the Transvaal which are not highly suitable for saligna, for example Driekop and Piet Retief. The mean site index in these areas can be estimated at VI. It is assumed that the area of this last group of plantations covers 20% of the total area of saligna plantations in South Africa.

The increment data derived from the yield tables have to be reduced by 10%, because the average degree of stocking is below 100. The estimated production is therefore:

Zululand ...	50,000	acres site index V	—13.5 mill. cu. ft./annum.
Transvaal ...	36,000	acres site index VI	— 8.1 mill. cu. ft./annum.
	155,516	acres site index IV	—54.6 mill. cu. ft./annum.
		Total	76.2 mill. cu. ft./annum.

Mean increment 315 cu. ft./acre/annum.

The estimated annual increment therefore is 11% more than the figures of Van Eck. The results obtained by Bosman are probably too low, but to allow for a safety margin a mean increment of 280 cu. ft. per acre per annum is assumed.

This increment is considerably higher than the mean volume increment per acre for countries in the Northern Hemisphere. The following figures have been derived from the publication "World Forest Resources" of the FAO (1955).

Country	Mean Volume Increment cu. ft./acre (average of all species)
United States of America	31
Canada	9
Great Britain	43
Germany	54
Denmark	96
France	43
Netherlands	37

It is seen, that the mean increment of saligna in South Africa is 190% more than the mean increment in Denmark, the country which reaches the highest increment per acre in Europe.

When the total area of saligna plantations is 241,516 acres, (Bosman 1956), and the mean increment 280 cu. ft. per acre per annum, the total annual increment is 68 million cu. ft.

The age class distribution of saligna plantations is approximately normal, but this is not the case in pine plantations. The annual cut in the pine plantations is less than the annual increment. The total output of timber from South African plantations has developed as follows (Bosman 1956).

1950—1951:	73,549,000	cu. ft.
1951—1952:	74,864,000	,,
1952—1953:	83,820,000	,,
1953—1954:	101,209,000	,,

The annual consumption of fuel wood is estimated at 30 million cu. ft. De Villiers (1954) estimates the total quantity of timber, produced in 1950, at 100 million cu. ft. (including production of fuel wood).

Applying the figures of Bosman and De Villiers, the total timber production in 1958 can be estimated at 160 million cu. ft. The implication is that saligna has produced 42% of the total production in South Africa.

The estimated production of home-grown timber is probably too low, so that the proportion of saligna in the total production is high. These figures show, however, that saligna obviously makes an important

contribution to the present timber production of South Africa. When the age class distribution becomes more normal the proportion of saligna in total timber production will decrease gradually.

When the value of the timber is put at R0.08 per cu. ft. the total annual volume increment has a value of R5.4 million. This corresponds to 0.18% of the national income for 1954.

The economic prospects for the production of saligna timber must be considered against the background of the development of timber production and timber consumption in S. Africa. The quantity of timber consumed in any country is dependent on the following factors:

(1) Number of inhabitants.

(2) Standard of living.

(3) Quantity of timber which is available.

The population of S. Africa has been increasing as follows (Yearbook of Union of S. Africa 1956—1957):

1904:	5.2	million	inhabitants.
1911:	6.0	,,	,,
1921:	6.9	,,	,,
1936:	9.6	,,	,,
1946:	11.4	,,	,,
1951:	12.7	,,	,,
1957:	14.2	,,	,,

Timber consumption in 1950 was 12.9 cu. ft. per capita (De Villiers 1954). In 1955 it was approximately 230 million cu. ft. or 16.8 cu. ft. per capita (Bosman 1956). This rise is probably due to increased industrial development in the Union. The present consumption, however, is still well below the average for most countries of the Northern Hemisphere. The following figures are derived from the "Yearbook of Forest Product Statistics" of the FAO (1957).

Country	Timber consumption cu ft. per capita
United States of America	120
U.S.S.R.	100
Great Britain	39
Germany	38
Sweden	117
Netherlands	38

Increase in timber consumption in South Africa will keep pace with the development of the non-Europeans. The total population will be approximately 25 million in the year 2000. If the timber consumption per capita is estimated at 25 cu. ft. in 2000, the total requirements which

are 230 million cu. ft. at present, will rise to 625 million cu. ft. in 2000. Van Eck gives the following estimated figures of timber production in the year 2000:

Pine plantations	1,900,000 acres, production	290 million cu. ft.
Gum plantations	600,000 acres, production	150 million cu. ft.
Wattle plantations	700,000 acres, production	90 million cu. ft.
	Total	530 million cu. ft.

If this estimate is approximately correct, then South Africa will not be self-supporting by the end of the century. Export of pulp and board products, moreover, will increase considerably, so that South Africa will still have to import large quantities of building and structural timber at the end of the century. Van Eck prophesies that the area of eucalyptus plantations will double by the end of the century. It is unlikely that the area of slow-growing eucalyptus species will alter appreciably so that if Van Eck is correct the area of saligna must rise from 241,000 to approximately 480,000 acres. Total saligna timber production will therefore increase to 134 million cu. ft. per annum.

This forecast raises the question of over-production of saligna.

The demand for saligna mining timber will probably be maintained. The demand for saligna pulpwood for the production of paper will increase by approximately 8—10 million cu. ft. The demand for timber for the manufacture of rayon pulp will also increase.

The market for saligna timber is not yet saturated and, as production of paper, rayon pulp, and board products increases, so will the demand for saligna timber increase. An expansion of the saligna area by 40—60,000 acres seems therefore justified. But on the basis of present and forseeable demands of industry it is not possible to justify an increase of 240,000 acres and it is considered that such an increase could lead to overproduction.

The market prospects for saligna saw timber have not improved during the last ten years, but this is partly due to the fact that the timber is not of very high quality. In previous chapters some silvicultural factors influencing the quality of the timber, particularly pruning and thinning have been discussed. The quality is also dependent on the handling of the timber after felling.

To obtain a better quality timber, an improvement of existing silvicultural methods must be combined with thorough technological investigations. This may lead to an increased demand for saligna sawtimber, which in turn would justify a further expansion of timber production.

CHAPTER X

PRACTICAL RECOMMENDATIONS

1. *SITE AND GROWTH:*

Volume production is chiefly influenced by rainfall and temperature. A superior growth can be expected in the humid parts of the

summer rainfall zone in the Northern Transvaal and in those parts of the subtropical summer rainfall zone in Zululand which are characterised by a high rainfall of 55—60 inches per annum. A moderate growth is to be expected in the Eastern Transvaal and in those parts of Zululand which have an annual rainfall of 40—50 inches. An inferior growth occurs in the Driekop forest reserve, characterised by a high rainfall, but low absolute minimum temperature and a wide daily range of temperature. When rainfall and temperature are the same, growth is influenced also by the soil type, the loamy soils in the Transvaal giving a better growth than the sandy soils in Zululand, and deep, well-drained soils are more suitable than shallow soils.

2. *SOIL PREPARATION:*

In afforestation of old agricultural land, a complete cultivation of the soil by means of ploughing, followed by harrowing is recommended. Partial cultivation, with rotary cultivator, as is sometimes practised in Zululand gives results which are not as good, and planting in pits, without further cultivation, should be avoided whenever possible. The latter method gives good results when a saligna stand is replanted and in such cases an intensive cultivation does not seem to affect the growth appreciably.

3. *ESPACEMENT:*

An espacement of 9 x 9 feet is recommended for saw timber plantations and for the independent timber producers, who grow pulpwood and mining timber. An espacement of 7 x 7 feet is recommended for plantations, which are associated with the pulpwood industry.

4. *REGENERATION:*

Coppicing can be recommended for plantations, producing mining timber and pulpwood. In general, replanting should follow the third coppice generation. Coppicing cannot be recommended for saw timber plantations, managed on a long rotation, but one or two generations coppice in saw timber plantations managed on short rotation is feasible. Volume production decreases with increasing number of coppice generations, but this decrease of production can be obviated by leaving two shoots per stool instead of one. This system can be recommended for mining timber and pulpwood plantations, in stands with a low number of stems per acre, but not for saw timber plantations.

5. *THINNING:*

Heavy thinnings, starting early, repeated at regular intervals, are recommended. A thinning scheme is given in table 8.

6. *PRUNING:*

In the production of saw timber it is recommended that prunings should be made immediately after the first and second thinning. They involve the pruning of all the remaining trees in the stand to half the tree height.

7. *ROTATION:*

It is recommended for mining timber and pulpwood production to apply a rotation which corresponds with a maximal earned rate of interest. The length of this rotation, being different for the Transvaal and Zululand and different for various site indices is given in table 35. In saw timber plantations a short rotation of 12—14 years is to be preferred to a long rotation of 20—25 years.

SUMMARY

In this publication the results of an investigation into the silvicultural and economic aspects of E. saligna plantations in South Africa have been discussed.

CHAPTER I gives a brief description of the climate of the natural range of E. grandis and E. saligna and of the regions in which plantations have been established in South Africa. The injurious agencies are discussed.

In CHAPTER II there is a summary of the silvicultural methods employed in South African plantations.

In CHAPTER III the stem form and bark thickness of E. saligna are discussed. The results are summarised in a taper table and a bark volume table. The shape of the cross-section of stems in Zululand is discussed.

CHAPTER IV gives an analysis of the factors affecting growth. The following are the problems discussed: relation between site and growth, soil preparation, growth of planted stands, as compared with coppice, growth of successive generations coppice, influence of vertical mixture in the growth of coppice and espacement.

In CHAPTER V thinning and pruning in saw timber plantations are discussed.

CHAPTER VI gives the result of yield investigations in the form of yield tables for unthinned and thinned stands. Tables, giving frequency and volume distribution over d.b.h. classes have been prepared.

In CHAPTER VII the working technique of felling and subsequent primary conversion is discussed. Time tables have been constructed and labour costs analysed.

CHAPTER VIII gives the result of economic computations. The most profitable rotation in various circumstances is discussed and the monetory

yield and costs of a normal forest are analysed. Tables giving the effect of changed prices and costs on the land expectation value are included.

In CHAPER IX timber production in E. saligna plantations in South Africa is discussed from a national viewpoint.

CHAPTER X gives practical recommendations.

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THE CRANIAL ANATOMY AND KINESIS OF THE BIRD SNAKE THELOTORNIS CAPENSIS (SMITH)

BY

J. G. I. VISSER

14. [illegible] [illegible] [illegible] [illegible] [illegible]
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